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PETROLOGY.—*Thermochemistry of mineral substances, I: A thermodynamic study of the stability of jadeite.* F. C. KRACEK, K. J. NEUVONEN,[1] and GORDON BURLEY, Geophysical Laboratory.

The sodium alumino-silicate compound $NaAl(SiO_3)_2$, which in its natural crystalline form is known as the mineral jadeite, has not yet been crystallized in the laboratory. All attempts to devitrify a melt of this composition to jadeite, as well as attempts to produce the compound by more elaborate methods, have failed. The various experimental trials, both dry and hydrothermal, are discussed in detail, together with references in a paper by Yoder (1950). Earlier it was shown in a paper by Greig and Barth (1938) that a dry melt of jadeite composition crystallizes to nepheline and albite, with a solidus at 1068° C. and a nepheline liquidus at 1138°. It was further shown that a natural jadeite from Burma (U.S.N.M. no. 94303) began to melt metastably as low as 800° and yielded nepheline and melt at 1015°, with the conclusion that jadeite was unstable under the conditions of the experiment. Schairer and Merwin (unpublished, 1948) showed that the melt crystallizes into albite and nepheline with a liquidus at 1128° C. (Yoder, 1950, p. 319).

Jadeite could conceivably be formed by the following solid-state reactions:

Reaction A $NaAlSi_3O_8$ (albite) $= NaAl(SiO_3)_2$ (jadeite) $+ SiO_2$ (quartz)

Reaction B $NaAlSiO_4$ (nepheline) $+ NaAlSi_3O_8$ (albite) $= 2\ NaAl(SiO_3)_2$ (jadeite)

Reaction D $NaAlSiO_4$ (nepheline) $+ SiO_2$ (quartz) $= NaAl(SiO_3)_2$ (jadeite)

In all three of these reactions, advance from left to right, as written, would proceed with a decrease in volume, and hence would be favored by increase of pressure. However, experiments at pressures up to 3,000 bars were not successful in producing jadeite. It will be shown below that reaction A tends to proceed in the reverse direction, from right to left, at ordinary temperature and pressure, but becomes favored in the forward direction (left to right) by the application of high pressure, while reactions B and D tend to advance from left to right at all pressures at 25° C. in the direction of producing jadeite. Deductions based on reaction B have led to establishing in the minds of petrologists the hypothesis that jadeite is a mineral formed under high pressures without the adequate realization that (a) even in a highly favorable case the application of high pressure produces only a relatively small contribution to the affinity of the process, as measured by the decrease in the free energy for the reaction; and (b) although the progress of a reaction may be favored by a decrease in the free energy, the advance may be hampered by the existence of passive resistances to change, more specifically, of high energy barriers (insufficient energies of activation) to such an extent that no advance may be possible. Such factors especially play a large role in reactions of silicates, as is well known. The influence of the kinetic factors mentioned has been clearly discussed in a recent text on petrology (Turner and Verhoogen,

[1] Visiting investigator of the Carnegie Institution of Washington associated with the staff of the Geophysical Laboratory. Member of staff of the Geological Survey of Finland. Present address, Department of Geology, University of Helsinki, Helsinki, Finland.

1951) to which reference may be made for the literature on the subject.

The above observations make clear the existence of a need for a thermodynamic study of reactions by which jadeite could be formed. It is the purpose of this paper to present the results of a study leading to the evaluation of the free energy changes for the reactions mentioned, A, B, and D, as well as for a fourth reaction C

Reaction C $\quad NaAlSiO_4 + 2\ SiO_2 = NaAlSi_3O_8$,
nepheline quartz albite

with the aim of establishing the possibility of the formation of jadeite in the absence of passive resistances to change, under the standard thermochemical conditions of 25°C. and atmospheric pressure. Included are considerations dealing with the influence of high pressure on the free energy changes, foundations for which were laid by the measurements of Yoder and Weir (1951), who, however, considered the effect of pressure on the formation of jadeite solely by reaction B.

The four reactions are interrelated as follows:

Reaction C = Reaction B − 2 Reactions A
Reaction D = Reaction B − Reaction A

These interrelations will be considered in some detail in a later section. It is appropriate to mention that the discussions of the four reactions are confined throughout to the solid phase reactions, wherein the passive resistances to change play a preponderant role. It is well known that no difficulties arise in the preparation of homogeneous melts of the composition of any of constituents of these reactions nor in the mixing of such melts to produce melts of intermediate composition. Difficulties are, however, encountered in the crystallization of such melts to produce the crystalline compounds, not only in the case of jadeite, as indicated, but with albite and quartz as well. The high energy barriers which are effective in delaying the crystallization of the melts are compounded in solid-phase reactions, and hence it is plausible to expect that the rate of reaction in such systems as are here considered would be exceptionally low.

OUTLINE OF THE THERMODYNAMIC TREATMENT

For reactions at constant temperature and pressure, combination of the first and second laws of thermodynamics yields as the fundamental criterion for equilibrium in a chemical reaction the condition that a function of state of the system called the free energy, F, in the nomenclature of Lewis and Randall (1923), be at a minimum. According to the adopted conventions a reaction not at equilibrium may tend to advance toward equilibrium with a decrease in the free energy.

The quantity F is defined as

$$F = E + PV - TS = H - TS \qquad (1)$$

where E is the internal energy, V the volume, S the entropy, and P and T the absolute pressure and temperature, respectively. The quantity H, called the heat content or enthalpy, is also a function of state of the system, like F, E, and S. Other definitions of F are employed for chemical systems to relate changes in F to the equilibrium constant of a reaction, or to the electromotive force of a galvanic cell in which the reaction may occur. For the present discussion other such definitions are not found to be suitable.

At constant temperature and pressure, the change in the standard free energy of a reaction, i.e., $\Delta F°$, for a reaction in which all the constituents are in their standard states (Rossini, 1951), is given by

$$\Delta F° = \Delta H° - T\Delta S° \qquad (2)$$

where Δ signifies a finite increment in the value of the quantity to which it is applied. According to (2), $\Delta F°$ may be evaluated from the separate measurements of $\Delta H°$ and $\Delta S°$.

$\Delta H°$ represents the quantity of heat which would be absorbed per mole of reaction if the reaction occurred at constant temperature and pressure in a calorimeter. Since none of the reactions considered will advance at an appreciable rate, a resort is made to dissolving each of the reaction constituents in a suitable common solvent, which in this case is hydrofluoric acid of 20.0 percent

strength, and measuring the heat of reaction for each of the solution reactions. $\Delta H°$ is then determined by a conventional combination of the separate thermochemical processes in accordance with the law of Hess.

The entropy change $\Delta S°$ is evaluated through application of the third law of thermodynamics to the low temperature heat capacities measured for each of the reaction constituents. The methods of evaluation are outlined by Kelley (1950).

THE CALORIMETER AND METHODS OF MEASUREMENT

A solution calorimeter designed for use at temperatures near 75° C. with hydrofluoric and other strong acids has been described by Torgeson and Sahama (1948). The calorimeter used in this investigation is of similar construction except for certain details. It is shown in Fig. 1, and a preliminary description of it with photographs of the parts has been given by Adams (1947, 1948, 1949). The calorimetric assembly is immersed in oil in a thermostatic bath to the level indicated at UU. The thermostatic bath is held at a temperature near 75° C. with a sensitivity of ca. + 0.02°. It is controlled by a "metastatic" mercury thermoregulator; the exact value of the mean bath temperature depends on the setting of the particular thermoregulator in use at any given time. During the course of this study the mean temperature of the bath was 74.7°.

The gold calorimeter vessel K of about 900 ml capacity is filled with 760 ml of 20.0 percent (by weight) reagent grade hydrofluoric acid, which is obtained by dilution of 48 per cent acid as received from the supplier in plastic bottles. All the acid used in the measurements reported here came from the same lot and was analyzed from time to time by titration with standard NaOH. The calorimeter vessel has four chimneys in its cover, one of which serves for dropping in samples through a bakelite tube, not shown in the diagram, and the other three for holding the stirrer CL and the resistance thermometer and calibrating heater, M and N, contained in the protecting gold wells F and G.

The resistance thermometer and the calibrating heater M and N are wound on thin-walled, hollow copper spools, which fit their protecting wells F and G very closely. Good thermal contact is secured by filling the intervening annular space with vacuum pump oil. One advantage of separate locations for the two coils is that the temperature of the calorimeter may be observed while the calibrating current is turned on.

The resistance thermometer is a coil of enameled and single silk-covered B. & S. gauge no. 40 copper wire. The calibrating heater is wound of double silk-covered B. & S. gauge no. 35 manganin wire. Both coils are adjusted to have resistances of ca. 100 ohms at the operating temperature. The calorimeter stirrer housing is made of Teflon; the

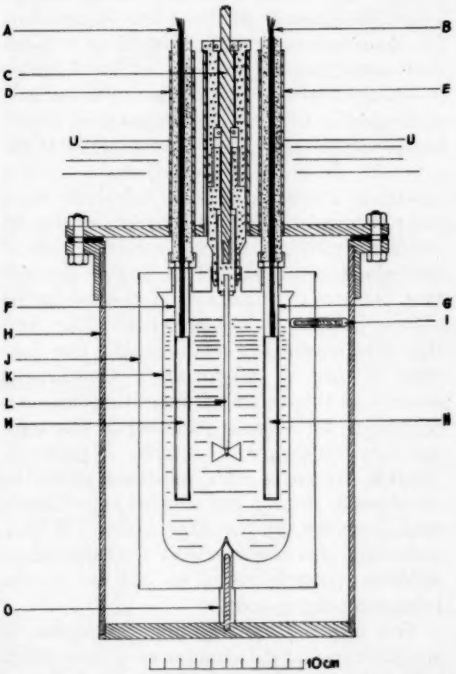

FIG. 1.—A solution calorimeter for use with hydrofluoric acid. A, B, leads from the resistance thermometer and calibrating heater; C, stirrer assembly; D, E, chimneys in the cover of the calorimeter jacket; F, G, protecting gold wells for the measuring instruments; H, calorimeter jacket; I, centering supports (three) for the calorimeter and radiation shield; J, radiation shield; K, gold calorimeter vessel; L, stirrer propeller shaft; M, N, resistance thermometer and calibrating heater; U, U, level of immersion in thermostat bath filled with oil; O, insulating support for calorimeter and shield.

shaft C rotates on two ball bearings as indicated and supports at its lower end the platinum propeller L by means of a Teflon coupling, which serves to block heat conduction.

Measurements with the resistance thermometer are made by means of a constant current "fixed arm" Wheatstone bridge circuit connected to a potentiometer for measuring the e.m.f. unbalance of the bridge. The bridge has two very nearly equal ratio arms of 2000 ohms each and a third arm adjustable in steps of 0.1 ohm; the thermometer is connected as the fourth arm with current and compensating leads. An accurate plug-type resistance box, made by Otto Wolff, Berlin, was used for the bridge arms. Provision is made in the connections for observations in either the N or R position, according to the code of the Mueller resistance thermometer bridges. The current through the bridge is maintained at 0.004 amp. with a sensitivity approaching 0.001 per cent. In practice the adjustable arm is pre-set at a resistance of ca. 0.3 ohms lower than the resistance of the thermometer at the temperature at which the cooling rate of the calorimeter is zero. This is done in order that the e.m.f. unbalance of the bridge be always positive in a selected direction, and that it be reasonably small (usually less than 1000 μv [μv = microvolts]). Unbalanced e.m.f.'s of this order of magnitude are calculated to be a linear function of the temperature difference to within 2 parts in 100,000, which is quite adequate since the calorimetric rises in the solution experiments have been usually less than 500 μv. With a particular thermometer coil 1° temperature difference corresponded to 634 μv in the bridge-unbalance e.m.f.

The electrical energy for calibration is supplied to the calorimeter at a rate which is comparable with the rate of generation of heat by the dissolving samples. The calibrating current is determined by measuring the potential drop across the terminals of a 0.1 ohm standard resistor in a circuit arrangement recommended by White (1910). In our set-up this involves shunting the heater coil by a series combination of a 10-ohm standard resistor and an accurate resistance box of 10,000-ohm range adjustable in steps of 0.1 ohm. By means of this circuit a known fraction of the potential drop through the heater may be measured, and thereby the resistance of the heater determined at the calorimeter temperature while the heater is carrying current. Energy input times in calibration were measured by reference to the time-signal clock of this Laboratory, with the energizing switch operated manually. A calibration is performed before or after each heat of solution experiment.

A White double potentiometer of 100,000 μv range is used for the potential measurements. This is carefully shielded against electrical leakage, which would produce significant errors in the measurements. The potentiometer is calibrated in international units, and is frequently standardized against a calibrated standard cell in terms of int. volts. We have for this reason retained the use of the international units in all the measurements and express the results in terms of the defined thermochemical calorie, 1 cal. = 4.1833 int. joules.

The samples to be dissolved in the calorimeter are contained in gelatine capsules (size 000), weighted down for rapid immersion in the acid by a platinum weight attached to the outside by means of a platinum wire hook. The capsules after weighing are kept at room temperature in a metal-lined box provided with a sensitive thermometer. Weights of the samples are corrected to weight in vacuum. The heats of reaction are adjusted to correspond to the process

Reactants (state specified, 25°)
→ Products (state, 74.7°),

by applying corrections to the observed heat of reaction per capsule and contents (a) for the heating up of the platinum sinkers from room temperature to 74.7°, (b) for the departure of the capsule and contents from 25°, and (c) for the heat of the process

Gelatine (amorph., 25°)
→ Gelatine (HF soln., 74.7°).

The heat capacity of platinum is taken as $c_p = 0.032$ cal/g and that of gelatine as 0.5 cal/g. The heat of reaction of gelatine in the above process was measured and found to be $\Delta H = 22.2 \pm 0.4$ cal/g. The purpose of these corrections is to obtain heats of

reaction which by the addition of thermochemical equations will yield values for combination reactions at the conventional thermochemical reference temperature of 25° C.

The measurements of the calorimeter temperature were corrected for heat exchange with the surroundings by a procedure based on Newton's law.

Corrections for the impurities in the samples were applied as demanded by the indications of the analyses. In preparation for making corrections for plus water (water not driven off at 110°) measurements were made of the process

$$\text{Water (1., 25°)} \rightarrow \text{Water (HF soln., 74.7°)}; \quad \Delta H = 788 \pm 5 \text{ cal/mole}$$

and 1438 cal/mole added for the heat of melting, to result in

$$\text{Water (ice, 25°)} \rightarrow \text{Water (HF soln., 74.7°)}; \quad \Delta H = 2226 \text{ cal/mole.}$$

The ice correction was employed on the assumption that plus water is retained in the minerals as a solid.

THE MATERIALS

The materials used in this study are described below:

Albite, Amelia, Va. Supplied by the U. S. National Museum, no. 5390. This could be obtained of good purity by hand picking.

Albite, Varuträsk, Sweden. Supplied by Th. G. Sahama. This contained numerous inclusions which were separated after crushing by magnetic separation, flotation, and centrifugation in heavy liquids.

Jadeite, Burma. Supplied by the U. S. National Museum, no. 94829. A cylinder from the sample was used in compressibility measurements, Adams and Gibson (1929), Yoder and Weir (1951). H. E. Merwin found the material to be practically pure jadeite. Crushed rock was purified by flotation in heavy liquids by L. H. Adams for use in measurements of low temperature heat capacities and heats of solution.

Jadeite, Japan. Specimen from Kotaki, Japan. USNM no. 105860. This specimen contained liquid inclusions, analcite, tremolite, and albite. Crushed rock was purified by centrifugation in Clerici solution, followed by further separations in Clerici solution with high frequency low amplitude agitation.

Quartz, Lisbon, Md. Collected by C. N. Fenner and J. W. Greig. Crushed and treated with hydrochloric acid by General Chemical Co. Residue of 0.03 percent after evaporation with HF + H_2SO_4.

TABLE 1.—RESULTS OF CHEMICAL ANALYSES OF THE MATERIALS

Material	Albite Varuträsk	Albite Amelia	Jadeite Burma	Jadeite Japan	Nepheline Synthetic
Analyst*	Zies	Chad.	Zies	K.	B. M.
SiO_2	68.76	67.84	59.51	58.96	42.42
TiO_2	0.00	0.00	0.01	0.00	0.01†
Al_2O_3	19.50	19.65	24.31	24.10	35.92
Fe_2O_3	0.13	0.03	0.35	0.21	0.05†
FeO	n.d	0.02	0.03	0.00	
MgO	0.00	0.04	0.58	0.82	0.05†
CaO	0.13	0.00	0.77	1.12	0.05†
Na_2O	11.51	11.07	14.37	14.41	21.40
K_2O	0.13	0.29	0.02	0.11	0.1†
H_2O^+	0.08	0.56	0.06	0.28	
H_2O^-	—	0.30	—	0.02	
Other	0.02 P_2O_5		0.01 MnO 0.01 Cr_2O_3		
Total	100.26	99.80	100.03	100.03	100.00

* Names of analysts indicated by abbreviations:
Zies = E. G. Zies, Geophysical Laboratory
Chad. = E. Chadbourn, University of Minnesota
K. = Oleg von Knorring, University of Leeds
B. M. = Bureau of Mines, analysis furnished by K. K. Kelley
† Results of spectroscopic analysis in terms of the elements.

Quartz, S.I. Probable source, Sycamore Island in Potomac River. A bottle of this was furnished by E. S. Shepherd. Residue 0.06 percent after evaporation with HF + H_2SO_4.

Nepheline, synthetic. Prepared by J. F. Schairer.

Analyses of the purified materials are collected in Table 1.

The purified materials were prepared for dissolving in the solution calorimeter by grinding for about three hours in a power grinder, using either agate or mullite mortar and pestle. The resulting impalpable powder was then elutriated in distilled water, usually three times, with 10 minutes allowed for settling of the coarser particles. The finest fraction for use was then filtered off under suction on a heavy paper in a Buechner funnel and air dried before a final drying in an oven at 120° C. The elutriated powder tends to agglomerate into tiny fragile lumps. It was found that particularly jadeite and nepheline when elutriated tend not to dissolve smoothly in the calorimeter. In later experiments with unelutriated preparations it was found that these materials dissolved sufficiently rapidly for calorimetric determinations and, hence, elutriation was avoided. This helped to eliminate not only the uneven solution rates, but other troubles as well. Thus, in some of the early experiments, residual lumps of a material which may have been undissolved sample, but which were identified as chiolite, $5NaF \cdot 3AlF_3$, were found in the calorimeter. No such precipitates were found when unelutriated samples were used.

The molecular compositions of the materials were computed from the results of the analyses in the usual manner for the calculation of the norm, and the observed heats of solution corrected for the heats of solution of the small amounts of impurities found in the manner indicated by Torgeson and Sahama (1948).

MEASUREMENTS AND RESULTS

The heats of reaction $\Delta H^\circ_{298.16}$. The standard heats of reaction $\Delta H^\circ_{298.16}$ for the four chemical reactions A to D are obtained as resultants of summations of the heats of reaction of the individual solution reactions presented in skeleton form in Table 2. Conventionally, they represent heats of the formation reaction of the products on the right from the reactants on the left of the reaction as written. Thus, for reaction B, $\Delta H^\circ_{298.16}$ represents the heat of formation of two moles of jadeite from one mole of nepheline plus one mole of albite, the heats of formation of which are taken as zero. Heats of formation from the elements are derivable from these heat values by addition of the heats of formation of the reactants from the elements. Measurements are in progress which will permit such computations to be made.

The reader may be reminded that solution reactions are destruction reactions for the constituents dissolved and hence that, in order to evaluate heats of formation of reactions A to D as indicated in the second part of Table 2, the summations must be performed as there outlined; that is, by subtracting the sum of the heats of solution of the products on the right from the sum of those of the reactants on the left of the chemical equation as written. For other examples, see Torgeson and Sahama (1948) and King (1951).

The uncertainties are stated in terms of the standard deviation according to the recommendations of Rossini and Deming (1939). Attention may be directed to the two values given for the heat of solution of Japanese jadeite. These represent values for the material ground in agate in the one case, and ground in mullite in the other. A value for the average of the two is given with its consequent very great uncertainty. It is possible that the two individual values represent jadeite made impure by the grinding; however, the loss of weight of the mortars and pestles was not determinable, and no reasonable computation could be made to allow for the silica and mullite presumably introduced as impurities. Hence only the average value is used in the computations.

The heat of solution value obtained for S. I. quartz, $-33{,}300 \pm 40$ cal/mole in 20.0 percent HF acid at 74.7°, may be compared with values for quartz obtained recently by others. Torgeson and Sahama (1948) obtained $-33{,}000 \pm 20$ cal/mole in 20.1 percent HF acid at 73.7°; King (1951) got $-33{,}290 \pm 80$ at 73.7° and $-32{,}810 \pm 90$ at 50° in 20.1 percent HF acid; and Sahama

and Neuvonen (1951), −33,240 ± 50 in 20.1 percent acid at 75.1°. Our value for quartz, Lisbon, Md., is −33,130 ± 30 cal/mole in 20.0 percent acid at 74.7°. The difference in the values for the Lisbon and the S. I. quartz is apparently a characteristic of the substances, just as differences are found for the two albites and the two jadeites, all after correction for impurities.

The individual heat of reaction values, $\Delta H°_{298.16}$, for the four reactions A to D, obtained by combinations of the thermochemical equations (1) to (4) of Table 2, are given in the first column of Table 4.

The entropies.—The values of the entropies $S°_{298.16}$ of the four materials for this problem were determined from measurements of the low temperature heat capacities at the Pacific Station of the Bureau of Mines by Kelley and Todd, who will publish the detailed measurements. We are permitted to use the results through the courtesy of Dr. Kelley. The data and their resultants for the reactions A to D are given in Table 3.

The free energy changes.—Combinations of the heat of reaction values $\Delta H°_{298.16}$ with the corresponding $-T\Delta S°_{298.16}$ values from Tables 3 and 4 according to the thermodynamic relation (2) yield the values of the free energy changes $\Delta F°_{298.16}$ for the reactions A to D as given in the last column of Table 4. Because of the smallness of the resultant heats of reaction for all of the reactions in question and the rapid accumulation of thermochemical errors, the uncertainty is in some cases greater than the net value of the heat of reaction $\Delta H°_{298.16}$. Nevertheless, it appears clear that within the relatively large error the combinations of the heat and entropy terms result in free energy decreases for reactions B, C, and D, and in an increase for reaction A. The re-

TABLE 2.—HEATS OF REACTION OF THE MATERIALS STUDIED

Reaction		kcal/mole ΔH	Uncertainty
(1) $NaAlSi_3O_8$ (c, 25°) + 22HF (soln., 74.7°) → NaF (soln., 74.7°)			
Albite			
+ AlF_3 (soln., 74.7°) + $3H_2SiF_6$ (soln., 74.7°) + $8H_2O$ (soln., 74.7°)			
	Amelia	−149.79	0.11
	Varu.	−148.12	0.21
(2) $NaAlSiO_4$ (c, 25°) + 10HF (soln., 74.7°) = NaF (soln., 74.7°) + AlF_3 (soln., 74.7°)			
Nepheline			
+ H_2SiF_6 (soln., 74.7°) + $4H_2O$ (soln., 74.7°)			
	synthetic	− 87.33	0.21
(3) $NaAl(SiO_3)_2$ (c, 25°) + 16HF (soln., 74.7°) = NaF (soln., 74.7°)			
Jadeite			
+ AlF_3 (soln., 74.7°) + $2H_2SiF_6$ (soln., 74.7°) + $6H_2O$ (soln., 74.7°)			
	Burma	−114.96	0.35
	Japan, ground in agate	−114.35	0.09
	Japan, ground in mullite	−115.93	0.17
	Japan, av.	−115.14	0.79
(4) SiO_2 (c, 25°) + 6HF (soln., 74.7°) = H_2SiF_6 (soln., 74.7°			
Quartz	Lisbon, Md.	−33.130	0.030
+ $2H_2O$ (soln., 74.7°)	S.I.	− 33.300	0.040

Reaction A

$NaAlSi_2O_8$ (c, 25°) = SiO_2 (c, 25°) + $NaAl(SiO_3)_2$ (c, 25°)
Albite quartz jadeite

$\Delta H_A = \Delta H_1 - \Delta H_3 - \Delta H_4$

Reaction B

$NaAlSi_2O_8$(c, 25°) + $NaAlSiO_4$(c, 25°) = $2NaAl(SiO_3)_2$(c, 25°)
Albite nepheline jadeite

$\Delta H_B = \Delta H_1 + \Delta H_2 - 2\Delta H_3$

Reaction C

$NaAlSiO_4$(c, 25°) + $2SiO_2$(c, 25°) = $NaAlSi_2O_8$(c, 25°)
Nepheline quartz albite

$\Delta H_C = \Delta H_2 + 2\Delta H_4 - \Delta H_1$

Reaction D

$NaAlSiO_4$(c, 25°) + SiO_2(c, 25°) = $NaAl(SiO_3)_2$(c, 25°)
Nepheline quartz jadeite

$\Delta H_D = \Delta H_2 + \Delta H_4 - \Delta H_3$

TABLE 3.—ENTROPIES

Data supplied by K. K. Kelley

Material	$S°_{298.16}$	*eu/mole*
$NaAlSi_3O_8$ (albite, Varuträsk)	49.2	±0.3
$NaAlSiO_4$ (nepheline, synthetic)	29.1	±0.2
$NaAl(SiO_3)_2$ (jadeite, Burma)	31.8	±0.2
SiO_2 (quartz)	10.0)	0.1

Reaction	$\Delta S°_{298.16}$	
A. $NaAlSi_3O_8 = NaAl(SiO_3)_2 + SiO_2$	−7.4	±0.4
B. $NaAlSiO_4 + NaAlSi_3O_8 = 2NaAl(SiO_3)_2$	−14 7	±0.5
C. $NaAlSiO_4 + 2SiO_2 = NaAlSi_3O_8$	0.1	±0.4
D. $NaAlSiO_4 + SiO_2 = NaAl(SiO_3)_2$	−7.3	±0.3

sults signify that in the absence of passive resistances to change, reactions B, C, and D would advance as written, from left to right, whereas reaction A would advance in the opposite direction, from right to left, and would result in combining jadeite and quartz to form albite.

The decrease in free energy for reaction C is in good accord with petrological deduction from systems studied at higher temperatures, and also with field evidence in nature, where nepheline and quartz appear not to be found in intimate association.

INFLUENCE OF PRESSURE ON ΔF

For an isothermal reaction the influence of a change in pressure on the change in the free energy of reaction is given by

$$d\Delta F_T = \Delta V dP_T \qquad (3)$$

where the subscript T denotes constancy of temperature. The equation (3) can be integrated if the volumes of the reaction constituents are known as functions of pressure. For reaction B the data on jadeite, nepheline, and albite have been secured and evaluated by Yoder and Weir (1951) who included in their discussion the effect of thermal expansion in addition to that of compressibility. For the other three reactions, A, C, and D, discussed in this paper, there are needed, in addition, data for quartz, which are already available in the literature. The density of quartz at 25° may be taken as 2.647 g/cm³ from the work of Johnston and Adams (1912). From the data on the compressibility of quartz the volume compression at 20°, $\Delta V/V_o = -2.70 \times 10^{-6}P + 20.4 \times 10^{-12}P^2$ as evaluated by Birch (1942) for pressure P in bars from the measurements of Adams and Williamson (1923). Accordingly, $V_{25°} = 22.69$ cm³/mole and the molar volume at 25° and the pressure P bars is $V_P = 22.69 - 0.613 \times 10^{-4}P + 0.463 \times 10^{-9}P^2$ cm³/mole. From this datum and the data of Yoder and Weir for jadeite, nepheline, and albite, converted to express P in bars instead of atm, we obtain the following volume changes for reactions A, B, C, and D:

$$\Delta V_A = -17.28 + 1.083 \times 10^{-4}P - 1.90 \times 10^{-9}P^2 \qquad (4)$$

$$\Delta V_B = -33.66 + 2.369 \times 10^{-4}P - 2.78 \times 10^{-9}P^2 \qquad (5)$$

$$\Delta V_C = +0.90 + 0.200 \times 10^{-4}P + 1.01 \times 10^{-9}P^2 \qquad (6)$$

$$\Delta V_D = -16.38 + 1.283 \times 10^{-4}P - 0.88 \times 10^{-9}P^2 \qquad (7)$$

and the corresponding free energy changes in thermochemical calories at 25° and at the pressure P in bars:

$$\Delta F_A = \Delta F_{OA} - 0.4130P + 1.294 \times 10^{-6}P^2 - 15.1 \times 10^{-12}P^3 \qquad (8)$$

$$\Delta F_B = \Delta F_{OB} - 0.8045P + 2.83 \times 10^{-6}P^2 - 22.2 \times 10^{-12}P^3 \qquad (9)$$

$$\Delta F_C = \Delta F_{OC} + 0.0215P + 0.239 \times 10^{-6}P^2 + 8.1 \times 10^{-12}P^3 \qquad (10)$$

$$\Delta F_D = \Delta F_{OD} - 0.3915P + 1.53 \times 10^{-6}P^2 - 7.0 \times 10^{-12}P^3 \qquad (11)$$

where the ΔF_o terms, the constants of integration, are the free energy changes $\Delta F°_{298.16}$ at the pressure of 1 atm (effectively zero pressure in considering effects of high pressures) given in the last column of Table 4 for the different reactions.

It will be noted that the ΔF for reactions B and D, already negative at 1 atm, will become more negative with the application of high pressures. Reaction C, which is not directly concerned with the stability relations of jadeite, is of interest in that its ΔF_C is almost uninfluenced by pressure. For reaction A, ΔF_A, which is positive at 1 atm, becomes negative at pressures ranging from ca. 1600 to ca. 6000 bars, depending upon the value chosen at 1 atm. This suggests the possibility that Japanese jadeite, often found in association with quartz, may have been formed at depth, but does not agree with field evidence, according to which Japanese jadeite may be a hydrothermal product, in which case depth is not critical (Yoder, 1951, personal communication).

INFLUENCE OF TEMPERATURE ON ΔF

For an isobaric process the influence of a change in temperature on the change in the free energy for a reaction is given by

$$d(\Delta F_P/T) = -(\Delta H/T^2)dT_P \qquad (12)$$

where the subscript P denotes constant pressure. The equation (12) can be integrated if the heat contents of the reaction constituents are known at different temperatures. For the reactions studied here only data on albite and quartz are available (Kelley, 1949) and hence the evaluation of the ΔF's as functions of temperature can not yet be made. It is planned to make the needed measurements on jadeite and nepheline in the near future.

DISCUSSION

The data presented in this paper lead to the conclusion that under favorable kinetic conditions—that is, in the absence of passive resistances to change—jadeite could be formed at 25° C. and atmospheric pressure by either reaction B or D. In nature, an exact ratio of the reactants such as is de-

TABLE 4.—MOLAL HEATS OF REACTION, ENTROPY, AND FREE ENERGY CHANGES*

$\Delta F°_{298.16} = \Delta H°_{298.16} - 298.16\ \Delta S°_{298.16}$

A					
Ab = Jd + Qu			kcal/reaction		
Ab	Jd	Qu	$\Delta H°_{298.16}$	$-T\Delta S°_{298.16}$	$\Delta F°_{298.16}$
Var	Bu	S.I.	0.14 ± 0.41	2.21 ± 0.11	2.35 ± 0.42
Var	Jp av	S.I.	0.32 ± 0.83	2.21 ± 0.11	2.53 ± 0.83
Am	Bu	S.I.	−1.53 ± 0.37	2.21 ± 0.11	0.68 ± 0.39
Am	Jp av	S.I.	−1.35 ± 0.81	2.21 ± 0.11	0.86 ± 0.81
B					
Ab + Ne = 2Jd					
Ab	Ne	Jd			
Var	synth	Bu	−5.53 ± 0.43	4.38 ± 0.15	−1.15 ± 0.45
Var	synth	Jp av	−5.17 ± 1.61	4.38 ± 0.15	−0.79 ± 1.62
Am	synth	Bu	−7.20 ± 0.41	4.38 ± 0.15	−2.82 ± 0.43
Am	synth	Jp av	−6.84 ± 1.60	4.38 ± 0.15	−2.46 ± 1.62
C					
Ne + 2Qu = Ab					
Ne	Qu	Ab			
synth	S.I.	Var	−5.81 ± 0.30	−0.03 ± 0.15	−5.84 ± 0.34
synth	S.I.	Am	−4.14 ± 0.24	−0.03 ± 0.15	−4.17 ± 0.29
D					
Ne + Qu = Jd					
Ne	Qu	Jd			
synth	S.I.	Bu	−5.67 ± 0.41	2.18 ± 0.09	−3.49 ± 0.41
synth	S.I.	Jp av	−5.49 ± 0.82	2.18 ± 0.09	−3.31 ± 0.82

* Abbreviations used:

Ab Am = Albite, Amelia, Va.
Var = Albite, Varuträsk, Sweden
Jd Bu = Jadeite, Burma
Jp v = Jadeite, Japan, average value
Ne synth = Nepheline, synthetic
Qu S.I. = Quartz, S.I.

manded by D would not likely obtain, and it may be instructive to consider a more detailed analysis of the possibilities. The free energy decreases for the three reactions B, C, and D range in the order $-\Delta F_C > -\Delta F_D > -\Delta F_B$ according to Table 4. Therefore, in the absence of passive resistances to change, reaction C would occur first in a reaction mixture of nepheline and quartz. This reaction would continue until one of the reactants was used up. If nepheline were exhausted first, the reaction would stop with albite and unused quartz remaining behind. The only possibility for further reaction now would be reaction A, but since ΔF°_A is positive at 25° and 1 atm, no further reaction would occur at atmospheric pressure. If, on the other hand, quartz were exhausted first, reaction C would come to a stop with albite and the unused nepheline remaining behind, and this mixture would react by reaction B to produce jadeite until finally the nepheline or albite was exhausted. At the end the residue would contain jadeite and albite or quartz, or jadeite and nepheline, depending upon whether the original molar ratio of quartz to nepheline was greater than 1 or less than 1, respectively. These reactions as outlined would go in the sequence: C followed by B. If for some reason reaction C were hindered, but not reaction D, the product of reaction D would be jadeite and unused quartz for any molar ratio of quartz to nepheline in excess of 1, and jadeite with unused nepheline for a ratio of less than 1.

In the case of both reaction B and D, the tendency to form jadeite would be increased by the application of high pressure, the corresponding changes in the free energy being represented by equations (9) and (11). High pressure, likewise, would favor the advance of reaction A from left to right, according to equation (8). For this reaction ΔF_A is positive at 25° and 1 atm, and changes sign to become negative at pressures of ca. 1,600 bars to ca. 6,000 bars, depending upon the particular materials which are reacting. At pressures higher than these a tendency would accordingly exist to dissociate albite and to form jadeite and quartz. Because of the interrelations among the four reactions in question, reaction A could not occur at any pressure in the presence of nepheline in the reaction mixture. It will be noted from equations (8), (9), and (11) that even in the most favorable case, that of reaction B, pressure produces only a small change in the free energy of the reaction, in this case the change being roughly -0.8 kcal/mole per 1000 bars. As was mentioned previously, reaction C is almost uninfluenced by pressure, the small effect, as represented by equation (10) being to favor the reverse reaction.

The reactions investigated in this study present an unusually severe test of thermochemical data in that the net heats of reaction and the corresponding free energy changes are small numbers, values of which in many instances are comparable with the accumulated errors of the summations of the heats of solution from which they are derived.

The net result of this study may be summarized in the statement that the formation of jadeite is thermodynamically feasible at 25° C. without the application of pressure. While it is true that pressure favors the process, its effect in any case is relatively small. The failure to produce jadeite in the laboratory cannot accordingly be ascribed to unfavorable energy relations, but must be due rather to non-thermodynamic factors, such as we have loosely termed passive resistances to change, and the problem of synthesis of jadeite becomes again essentially a problem in reaction kinetics of the solid state.

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ICHTHYOLOGY.—*Three new skates and a new chimaerid fish from the Gulf of Mexico.*[1] HENRY B. BIGELOW and WILLIAM C. SCHROEDER. (Communicated by Leonard P. Schultz.)

The U. S. Fish and Wildlife Service vessel *Oregon*, while engaged in a shrimp investigation in the Gulf of Mexico during the winter of 1950–51, caught a number of fishes that prove to be new to science. Stewart Springer, knowing of our interest in elasmobranchs and holocephalids, kindly sent us the specimens which we here describe. The holotypes and some of the paratypes are in the collection of the U. S. National Museum, while a representative of each species is in the collection of the Harvard Museum of Comparative Zoology.

Raja lentiginosa, n. sp.

Study material.—Male, 402 mm in total length, holotype, U. S. N. M. no. 153552, from the Campeche Bank, lat. 22° 32′ N., long. 88° 47′ W., in 29 fathoms, *Oregon* station 222; also four males and three females from the latter region and from the northern part of the Gulf of Mexico, lat. 28° 10′ to lat. 29° 11′ N. and long. 85° 00′ to 86° 52′ W. in recorded depths of 85, 112, 165, and 305 fathoms, including *Oregon* stations 256, 257, 278, and 279.

Distinctive characters.—*Raja lentiginosa* closely resembles *R. garmani* but may be distinguished by the color pattern of its upper surface, which is densely freckled with very small dark, light-brown, and whitish spots (sparse in *garmani* and mostly grouped in a distinct rosette pattern).

Description of holotype.—Proportional dimensions in percent of total length:

Disc.—Extreme breadth 60.0; length 46.5.

Snout length.—In front of orbits 9.2; in front of mouth 11.2.

Orbits.—Horizontal diameter 4.2; distance between 2.9.

Spiracles.—Length 2.1; distance between 6.2.

Mouth.—Breadth 6.5.

[1] Contribution no. 555 from the Woods Hole Oceanographic Institution.

Exposed nostrils.—Distance between inner ends 6.0.

Gill openings.—Lengths, first 2.0; third 1.9; fifth 1.2; distance between inner ends, first 13.9; fifth 7.0.

First dorsal fin.—Vertical height 3.0; length of base 5.6.

Second dorsal fin.—Vertical height 3.0; length of base 5.5.

Pelvics.—Anterior margin 12.2.

Distance from tip of snout to center of cloaca 39.2; from center of cloaca to first dorsal 45.3; to tip of tail 60.8; from rear end of second dorsal base to tip of caudal 2.9.

Interspace between first and second dorsals 1.2.

Disc about 1.3 times as broad as long, maximum angle in front of spiracles about 120°; anterior margins weakly convex from just posterior to tip of snout to opposite orbits, thence gently concave between spiracles and outer corners which are broadly rounded; posterior margins and corners and inner margins all rounded. Axis of greatest breadth about 68 percent of distance back from tip of snout to axils of pectorals. Tail with a lateral fold, low down on each side, beginning abruptly posterior to axils of pelvics a distance about equal to space between spiracles and continuing almost to extreme tip, width of fold about the same throughout its length; length of tail from center of cloaca to origin of first dorsal fin 1.15 times as great and to its tip 1.54 times as great as distance from center of cloaca to tip of snout.

Five prominent thorns along anterior edge of orbit, one opposite inner central margin and three along posterior margin, the last opposite spiracle, with an additional thorn inward from this one; a row of thorns over margins of rostral process; prickles and very small thorns are present over anterior third of disc in advance of nuchal region and extend along outer margin rearward to about axils of pectorals; a triangular patch of about 17 thorns on shoulder region, five of which extend along median line from nuchal to scapular region; a naked area behind these for a distance about equal to distance between spiracles. A band of three to five rather regular rows of thorns along median zone of back and on tail beginning in advance of axils of pectorals a distance about equal to that from eye to snout and ending at origin of first dorsal, the lowermost row reaching nearly to tip of tail; the median row, counting from nuchal region, consisting of 33 thorns, in most cases alternating large and small; most all the thorns on tail with sharp points, directed backward; one prominent thorn in space between dorsals; prickles on dorsal fins and caudal; skin over eye naked; a band of alar spines on outer part of each pectoral, in one to three rows, with 19 spines in longest row. Lower surface naked except for a small median patch of spines at extreme snout tip.

Snout in front of orbits 2.2 times as long as orbit, its length in front of mouth about 1.8 times as great as distance between exposed nostrils. Distance between orbits about 0.7 as great as length of orbit. Orbit twice as long as spiracle. Nasal curtain fringed; expanded posterior (outer) margins of nostrils fringed. Upper and lower jaws rather strongly arched centrally. Teeth $\frac{33}{32}$ close set, mostly in straight rows rather than in quincunx, with small base, circular or oval, those in median sector of mouth with slender sharp cusp pointing toward symphysis or inward toward throat, those in outer sector with triangular cusp pointing toward corner of mouth, one row of teeth at symphysis in upper jaw, pointing straight downward. Distance between first gill openings 2.3 times as great as distance between exposed nostrils; between fifth openings 1.2 times; first gill openings 1.6 times as long as fifth and 0.3 as long as breadth of mouth. First and second dorsals similar in size and shape. Interspace between dorsals 0.22 as long as base of first dorsal. Caudal membrane from rear end of base of second dorsal about half as long as base of first dorsal. Pelvics deeply concave, strongly scalloped along anterior side of excavation but only weakly so rearward; anterior margin only 0.55 as long as distance from its own origin to rear tip of pelvic; anterior lobe slender, including four radial cartilages besides the first stout one; posterior lobe moderately convex along its forward half, thence nearly straight to its narrowly rounded tip, extending a little more than one-fifth the distance from axil of pelvics toward first dorsal; inner margin straight. Claspers reaching beyond tips of pelvics by a distance about equal to diameter of orbit.

Rostral cartilage firm, extending nearly to tip of snout. Anterior pectoral rays reaching about seven-tenths the distance from front of orbits toward tip of snout.

Color.—Upper surface everywhere sprinkled with very small light to dark brownish and whitish spots, including the tail, pelvics and claspers; many groups of about 30–50 dark spots scattered everywhere, the most prominent marking being the group of spots at axil of pectoral, some of the spots on tail grouped in form of bars, there being

about five prominent bars; light and dark spots present on anterior part of each dorsal fin and on caudal. Below whitish with a group of grayish blotches, mostly fused, on each pectoral, and an elongate blotch along the inner part of the claspers anteriorly.

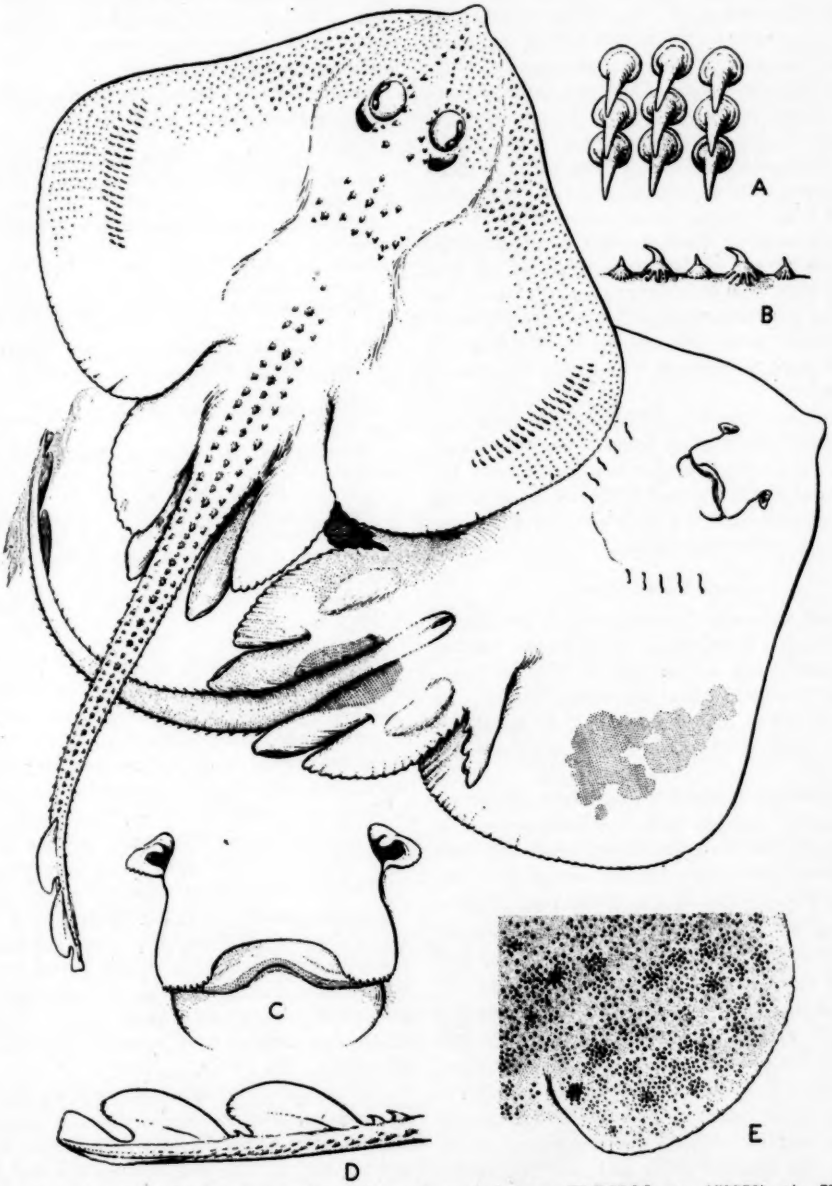

FIG. 1.—*Raja lentiginosa*, n.sp., male, 402 mm long, holotype (U.S.N.M. no. 153552): A, Upper teeth, about × 10; B, thorns on midrow of tail, about × 2; C, mouth and nostrils, about × 1.5; D, posterior part of tail, about × 1; E, section of upper surface to show color pattern.

A female 302 mm long differs slightly from the type by having no naked area on the midzone of back immediately behind shoulder region, but the thorns begin on the nape and extend without a break to the first dorsal, the rows being somewhat more irregular and the median row having about 45 thorns mostly of uniform size instead of alternating large and small. There is a patch of small thorns on the posterior part of the pectorals and a few on the pelvics and three thorns in the space between the dorsals. There are $\frac{11}{11}$ teeth, in quincunx, with low triangular cusp, none of which point toward symphysis or corners of mouth.

On a male of 232 mm the claspers extend a little beyond the tips of the pelvics, while on a *R. garmani* of 285 mm they fail to reach the tips of the pelvics by a distance as great as diameter of orbit. This male has 46 teeth in upper jaw and lacks the small patch of thorns on the extreme tip of snout below.

The few specimens of this species thus far captured have been taken over a wide depth range, from 29 to 305 fathoms. It is known from the northern part of the Gulf of Mexico in the offings of Pensacola and Cape San Blas and in the southern part on Campeche Bank.

Raja olseni,[2] n. sp.

Study material.—Immature male, 280 mm in total length, holotype, U. S. N. M. no. 153556, from lat. 27° 25′ N., long. 96° 13′ W., 76 fathoms, *Oregon* station 157 and an immature male, 282 mm, paratype, M. C. Z. no. 37176, from lat. 27° 27′ N., long. 96° 17′ W., 65 fathoms, *Oregon* station 158.

Distinctive characters.—*Raja olseni* closely resembles *R. laevis* in general appearance and in lacking thorns along the midbelt of the disc from the level of the axils of the pectorals to the vicinity of the spiracles. But it differs from *laevis* in having an interspace between the dorsal fins nearly or quite as long as the base of the first dorsal (only 0.1 to 0.3 that long in *laevis*); by having a fringe on the expanded outer margin of the nostril (smooth in *laevis*); also the lateral folds along its tail reach to only opposite the anterior third of the caudal fin, but in *laevis* extend almost or quite to the extreme tip of the tail; the lower sides of the disc are prickly along the anterior edges and over the rostral cartilage in *olseni* but smooth on *laevis* of equal size and its mucous pores are not marked with black as they are in *laevis*. It differs from *R. spinicauda* in its fringed nostril lobe, in its shorter tail folds, in the interspace between its dorsals, and in having three rows of thorns on the tail (only one row on *spinicauda*).

Description of holotype.—Proportional dimensions in percent of total length:

Disc.—Extreme breadth 69.0; length 54.0.

Snout length.—In front of orbits 15.6; in front of mouth 17.7.

Orbits.—Horizontal diameter 4.4; distance between 3.6.

Spiracles.—Length 2.0; distance between 6.3.

Mouth.—Breadth 7.9.

Exposed nostrils.—Distance between inner ends 7.9.

Gill openings.—Length, first 2.0; third 2.1; fifth 1.6; distance between inner ends, first 13.6; fifth 7.3.

First dorsal fin.—Vertical height 2.5; length of base 4.3.

Second dorsal fin.—Vertical height 2.4; length of base 4.6.

Pelvics.—Anterior margin 13.2.

Distance from tip of snout to center of cloaca 47.5; from center of cloaca to first dorsal 30.4; to tip of tail 52.5; from rear end of second dorsal base to tip of tail 3.2.

Interspace between first dorsal and second dorsal 4.3.

Disc about 1.3 times as broad as long, the maximum anterior angle in front of spiracles about 90°; anterior margins concave just posterior to tip of snout, weakly convex opposite eyes and spiracles, thence about straight rearward; outer corners narrowly rounded; posterior corners more broadly so; posterior margins gently convex. Axis of greatest breadth about 67 percent of distance back from tip of snout to axils of pectorals. Tail with a lateral fold, low down on each side, beginning posterior to axils of pelvics by a distance about four-fifths as long as eye and ending opposite anterior third of caudal fin, its length from center of cloaca to origin of first dorsal fin about 0.67 as great and to its tip about 1.1 times as great as distance from center of cloaca to tip of snout.

Two small thorns immediately in front of orbit, of which one is on the inner and one on the outer margin, also one on the inner rear margin; these are the only thorns or prickles on the disc. Sixteen thorns along midline of tail from a little in advance of axils of pelvics to first dorsal fin, and three in interspace between first and second dor-

[2] Named for Yngve H. Olsen in recognition of his excellent editorial work on Fishes of the Western North Atlantic.

sals. An additional row of thorns, widely and unevenly spaced, on each side of median row, beginning about opposite tips of pelvics and extending to opposite beginning of caudal fin; dorsals and caudal fin smooth. Lower surface with a narrow band of small prickles along anterior margin of disc from level of nostrils to tip of snout and also along rostral cartilage.

Snout in front of orbits 3.5 times as long as orbit, its length in front of mouth 2.2 times as great as distance between exposed nostrils. Distance between orbits 1.2 as great as length of orbit. Orbit 2.2 times as long as spiracle. Nasal curtain fringed; expanded posterior (outer) margins of nostrils fringed. Upper and lower jaws moderately arched centrally. Teeth $\frac{44}{44}$, close set in quincunx, ovate, with a triangular cusp. Distance between first gill openings 1.7 times as great as distance between exposed nostrils; between fifth gill openings 1.1 times; first gill openings 1.25 times as long as fifth and 0.25 as long as breadth of mouth. First and second dorsals similar in size and shape. Interspace between dorsals as long as base of first dorsal. Caudal

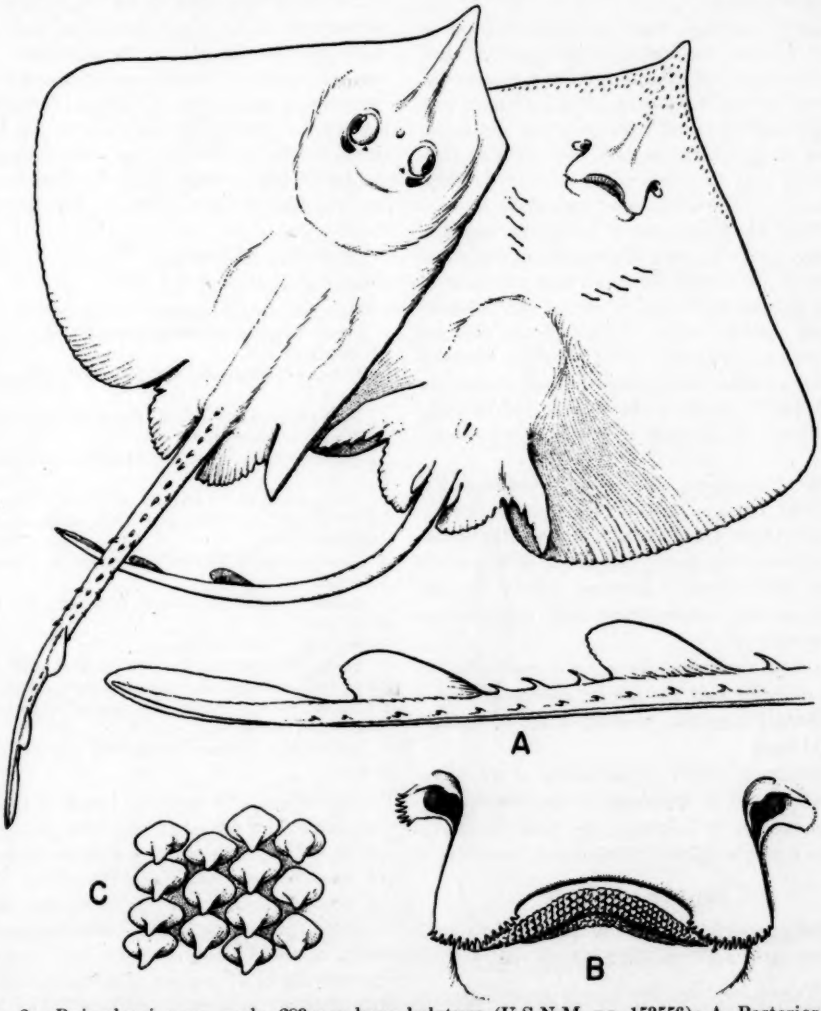

FIG. 2.—*Raja olseni*, n.sp., male, 280 mm long, holotype (U.S.N.M. no. 153556): A, Posterior part of tail, about × 1.5; B, mouth and nostrils, about × 2; C, upper teeth, about × 12.

membrane from rear end of base of second dorsal about twice as long as base of first dorsal. Pelvics deeply concave, strongly scalloped along anterior side of excavation but only weakly so rearward; anterior margin about as long as distance from its own origin to rear tip of pelvic; anterior lobe moderately slender, including five radial cartilages besides the first stout one; posterior lobe moderately convex outwardly; rear tips abruptly rounded, extending about two-sevenths the distance from axil of pelvics toward first dorsal; inner margin straight. Claspers falling well short of tips of pelvics.

Rostral cartilage firm, extending to tip of snout. Anterior pectoral rays reaching about half way from level of front of orbits toward snout tip.

Color.—Upper surface, in life, olive-brown with many small roundish obscure spots of darker brown on disc; a small dark spot, smaller than pupil, on each side of disc near its inward center; series of small whitish pores extend in three or four rows along midzone of back from region of pectoral girdle to axils of pelvics and extend on to tail in one or two rows; two rows extend rearward and outward on each side of disc posterior to the scapular region; whitish pores also are present opposite and in front of orbits, some extending toward outer margin of disc in sinuous rows. Below jet black everywhere, but this pigment tends to diminish in intensity in preservative.

The other known specimen of this species, 282 mm long, has a somewhat longer snout, the distance in front of orbits being four times the diameter of orbit; the interorbital space is as long as the orbit; the interspace between dorsals is nine-tenths as long as base of first dorsal and there are more teeth $\frac{1}{1}$.

As both specimens have very small claspers it is probable that the species attains at least a moderately large size, possibly 2 feet or more in total length.

Nothing is known of the habits of this skate except that it is apparently a moderately deep water species. It is known only from the northwestern part of the Gulf of Mexico as listed above.

Raja teevani[3], n. sp.

Study material. Immature male, 558 mm in total length, holotype, U. S. N. M. no. 153557, and an immature male 302 mm in total length, paratype, M. C. Z. no. 37189, both from lat. 29° 11′ N.; long. 86° 52′ W., in 305 fathoms, *Oregon* station 279.

Distinctive characters.—*Raja teevani* differs from all other rajids in the western North Atlantic in its broad tail, which widens rearward approaching the dorsal fins (in all other rajids it narrows rearward). It resembles *R. olseni* and *R. laevis* in general appearance and in lacking thorns along the midbelt of the disc from the level of the axils of the pectorals to the vicinity of the spiracles. But it differs from *olseni* by having no interspace between the bases of the dorsal fins; from *laevis* of comparable size it may be separated by its longer snout (the distance from tip of snout to eye being about one-fourth to one-third the width of the disc in *teevani* but only about one-fifth in *laevis*) and by the fact that the anterior margin of the pelvic fins is longer than the distance from its own origin to the rear tip of pelvic (shorter in *laevis*).

Description of holotype.—Proportional dimensions in percent of total length:

Disc.—Extreme breadth 72.7; length 58.2.

Snout length.—In front of orbits 22.2; in front of mouth 24.2.

Orbits.—Horizontal diameter 3.2; distance between 4.1.

Spiracles.—Length 2.0; distance between 6.1.

Mouth.—Breadth 7.7.

Exposed nostrils.—Distance between inner ends 8.7.

Gill openings.—Length, first 1.7; third 1.8; fifth 1.2; distance between inner ends, first 13.8; fifth 8.4.

First dorsal fin.—Vertical height 2.7; length of base 4.3.

Second dorsal fin.—Vertical height 2.7; length of base 4.0.

Pelvics.—Anterior margin 14.7.

Distance from tip of snout to center of cloaca 51.7; from center of cloaca to first dorsal 34.3; to tip of tail 48.3; from rear end of second dorsal base to tip of tail 5.4.

Interspace between first and second dorsals 0.0.

Disc about 1.25 times as broad as long, the maximum anterior angle in front of spiracles about 70°; anterior margins sinuous from snout to outer corners, being slightly convex a little in front of orbits; outer corners very sharply rounded; posterior margins gently convex; posterior corners broadly rounded. Axis of greatest breadth about 77 percent of distance back from tip of snout to axils of pectorals. Tail with a lateral fold low down on each side beginning al-

[3] Named for John Tee Van in appreciation of his helpful assistance to us as editor-in-chief of Fishes of the Western North Atlantic.

most imperceptibly about opposite tips of pelvics, widening rearward and ending opposite middle of caudal fin, its length from center of cloaca to origin of first dorsal fin 0.66 as great and to its tip 0.93 times as great as distance from center of cloaca to tip of snout.

Three small thorns along inner margin of left orbit, two of them anterior and one posterior; one anterior and one posterior thorn along inner margin of right orbit; minute prickles scattered over interorbital area and over entire disc anterior to the orbits. Tail with a median row of 15 backward pointing thorns, beginning about an eye's diameter posterior to the axils of pelvics and ending a little in front of first dorsal, the thorns somewhat more closely spaced and larger rearward than near their origin; minute prickles on tail from about tips of pelvics nearly to tip; dorsals and caudal with a few minute prickles. Lower surface with a band of prickles along anterior

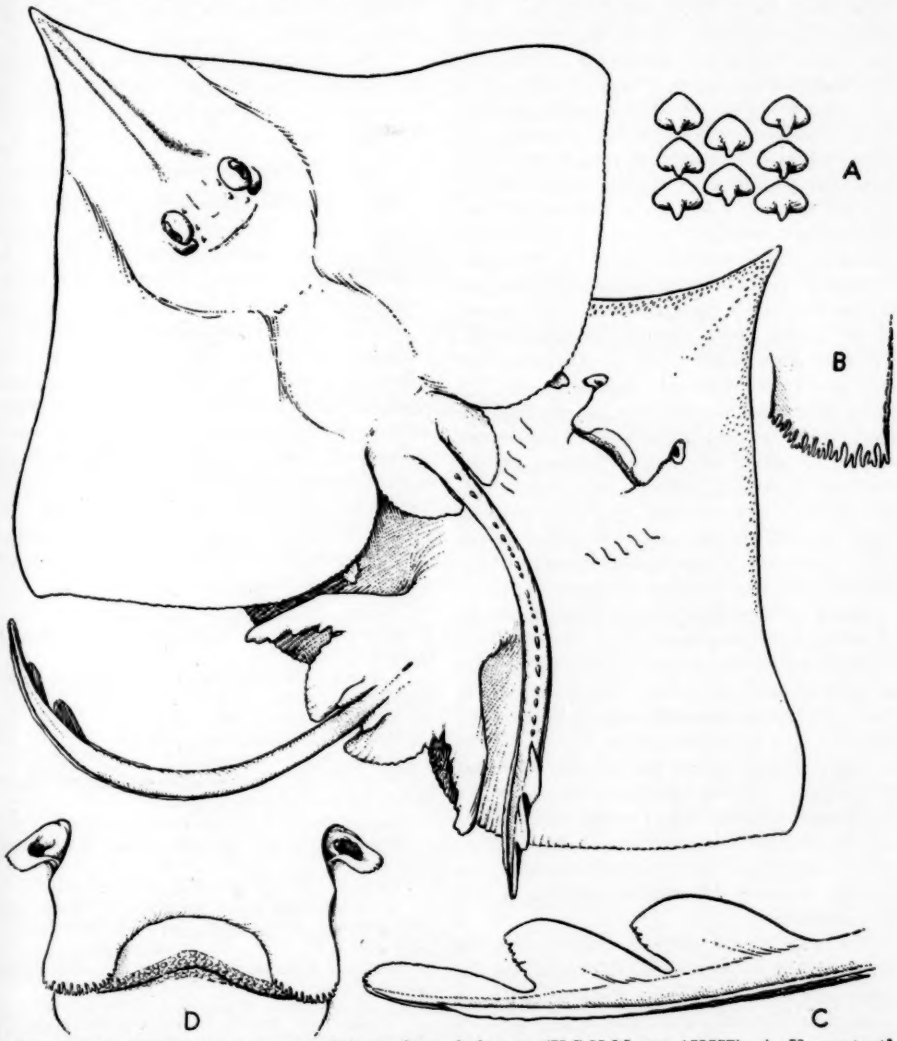

FIG. 3.—*Raja teevani*, n.sp., male, 558 mm long, holotype (U.S.N.M. no. 153557): A, Upper teeth, about × 6; B, margin of left nasal curtain about × 2.5; C, posterior part of tail, about × 1; D, mouth and nostrils, about × 1.

margin of disc from a little posterior to level of mouth to tip of snout and also along anterior half of rostral cartilage.

Snout in front of orbits 6.9 times as long as orbit; its length in front of mouth 3.6 times as great as distance between exposed nostrils. Distance between orbits 1.3 times as great as orbit. Orbit 1.6 times as long as spiracle. Nasal curtain fringed; expanded posterior (outer) margins of nostrils smooth except for a few fringes on extreme outer angle. Upper and lower jaws moderately arched centrally. Teeth $\frac{8}{8}\frac{8}{8}$, rather widely spaced, in quincunx, triangular or ovate, with smooth rounded apex on outward margin and a low triangular cusp, pointing inward, on inner margin. Distance between first gill openings 1.6 times as great as distance between exposed nostrils; between fifth gill openings about 1.0 times; first gill openings 1.4 times as long as fifth and 0.22 as long as breadth of mouth. First and second dorsals similar in size and shape. No interspace between dorsals. Caudal membrane from rear end of base of second dorsal 1.25 times as long as base of first dorsal. Pelvics deeply concave, strongly scalloped along anterior side of excavation but only weakly so rearward; anterior margin 1.1 times as long as distance from its own origin to rear tip of pelvics; anterior lobe moderately slender, including five radial cartilages besides the first stout one; posterior lobe convex outwardly; rear tips abruptly rounded, extending about one-fifth the distance from axil of pelvics toward first dorsal; inner margin straight. Claspers falling well short of tips of pelvics.

Rostal cartilage firm, narrow, extending to tip of snout. Anterior pectoral rays reaching only about two-fifths the distance from level of front of orbits toward tip of snout. Translucent area in front of orbits and on either side of rostral cartilage very thin and membranous.

Color.—Upper surface pale brown, somewhat darker along posterior margins of disc, on pelvics and on tail. Dorsal fins and caudal black. Below creamy on disc except somewhat dusky along outer margins from outer angle rearward and on pelvics. Probably blackish everywhere in life. Tail blackish.

The other known specimen of this species, 302 mm long, has a somewhat shorter snout, the distance in front of orbits being 5.5 times as long as orbit and a relatively longer tail the distance from center of cloaca to tip of tail being 1.1 times as great as distance from center of cloaca to tip of snout. There is one sharp backward pointing spine on the anterior inner margin of each orbit and another on the posterior inner margin. The color of the upper surface is similar to that of the type except that there is a narrow black margin along the posterior edge of the disc and the lower surface is distinctly margined with black rearward from the level of the mouth; the rear parts of the pelvics also are blackish.

The very small claspers on the larger specimen indicate that this species attains at least a moderately large size.

Nothing is known of its habits beyond the fact that our two specimens were taken at a depth of 305 fathoms. It is known only from the offing of Pensacola, Fla.

Hydrolagus alberti[4], n. sp.

Study material.—Immature male, 275 mm long to origin of upper caudal fin, holotype (U. S. N. M. no. 153558); male, 280 mm and female 275 mm, paratypes, all from lat. 29° 11′ N., long. 86° 52′ W., 305 fathoms, *Oregon* station 279.

Distinctive characters.—This newly discovered chimaerid is marked off from its genus mate *affinis* by its very long caudal filament, its relatively much longer pectorals, and its very much larger eyes. It resembles the Japanese *H. himitsukurii* very closely but differs from it by having a shorter dorsal spine, longer pectorals and more conspicuously waved lateral line anteriorly.

Description of holotype.—Proportional dimensions in percent of distance between snout and origin of upper caudal fin:

Trunk.—Breadth 10.9; height 15.6.

Snout length.—In front of eye 9.5; in front of mouth 10.5.

Eye.—Horizontal diameter 7.6; vertical diameter 5.8.

Mouth.—Breadth 5.5.

Nostrils.—Distance between 0.4.

Dorsal spine.—Length 15.3.

First dorsal fin.—Length of base to lowest point between dorsals 13.8.

Second dorsal fin.—Length of base 64.7.

Upper caudal fin[5].—Length of base to last horny ray 19.3.

Pectoral fin.—Length 31.6; breadth 16.3.

Distance from snout to origin of dorsal spine 24.4; second dorsal 38.2; pectorals 23.2; pelvics 45.5.

Distance from origin to origin of pectorals and pelvics 26.6.

[4] Named for Albert E. Parr in recognition of his many contributions to ichthyology.

[5] The point of origin of the lower caudal fin is not evident.

Trunk opposite dorsal spine about as high as distance from snout to posterior margin of eye; about one-half as high close behind pelvics, tapering evenly thence rearward and terminating in a long filament which, when complete, is about two-thirds the length of body from snout to termination of caudal fin; strongly compressed laterally posterior to head, increasingly so rearward, its thickness about three-quarters as great as its height opposite bases of pectoral fins and one-half as great opposite bases of pelvic fins.

Skin perfectly smooth on immature specimen.

Head about 21 percent of length of trunk to upper origin of caudal fin. Snout conical with blunt tip. Eye oval, sloping a little rearward, its horizontal diameter about 1.3 times its vertical diameter; distance from tip of snout to front of eye about two-fifths length of head to origin of pectorals; pupil one-half vertical diameter of eye; height of eye about two-fifths of height of head, its length about one-third length of head to origin of pectorals. Exposed subdivision of nostrils crescentic on inner edge, about 1½ times as long as broad, its length about 15 percent as great as length of eye; distance from its own rear edge to free edge of upper lip about as long as its own length. Width of mouth, when closed, a little less than length of eye.

Lateral mucous canal with a short and abrupt wave opposite the anterior part of first dorsal fin, after which there is a long low dip opposite origin of second dorsal fin, thence continuing nearly straight along the upper part of the caudal axis, descending at origin of caudal fin to follow out along lower edge of caudal axis. Junction of cranial canal with aural canal somewhat more acute than a right angle; anterior course of cranial canal nearly straight, looping down in front of eye;

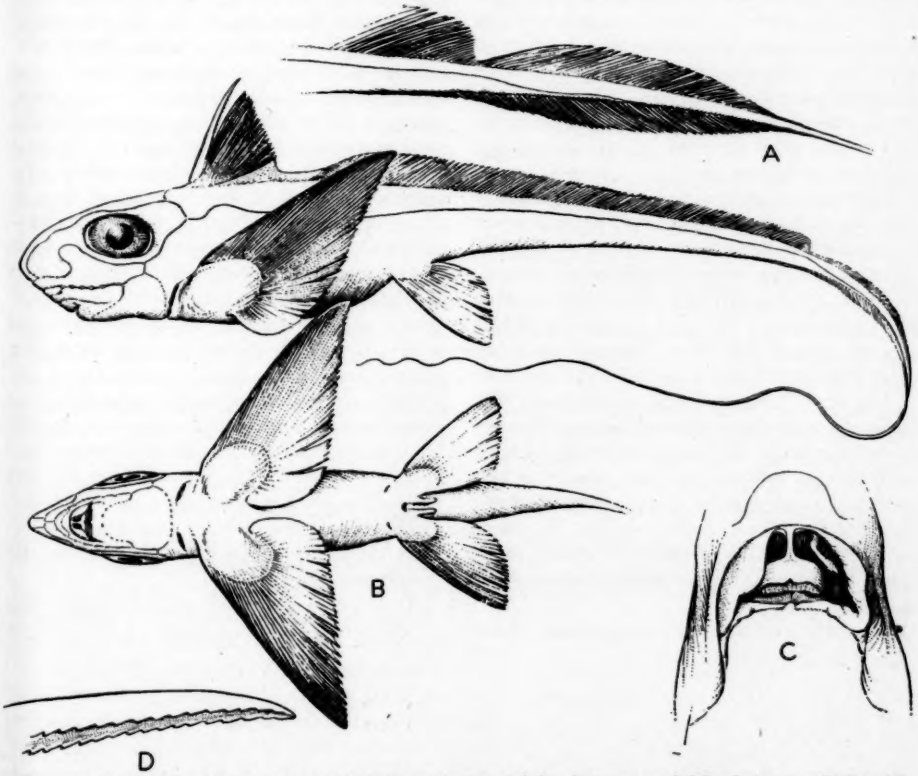

FIG. 4.—*Hydrolagus alberti*, n.sp., male, 275 mm long to origin of upper caudal fin, holotype (U.S.N.M. no. 153558): A, Posterior part of second dorsal fin and upper and lower caudal fins, about × 1; B, ventral view of head and body; C, mouth, with left lip folded aside to show nostrils and dental plates, about × 2; D, tip of dorsal spine, about × 2.5.

jugular and oral canals running downward from suborbital as a joint canal for a short distance before separating. About 10–12 medium size pores close in front of occipital canal; about 12 pores in area bounded by suborbital and joint oral-jugular canals; about 10 large openings along angular canal to front of snout; a single row of about 15 small pores parallel to descending oval branch and continuing in front of it; about 8 or 9 large openings along anterior part of suborbital canal from its descending wave to front of snout; jugular canal continued downward onto throat as a series of short slits. Skin closely pock-marked on top and on upper sides of head abreast of mouth and nostrils and toward tip of snout, with many rounded depressions of different sizes.

Anterior upper (vomerine) dental plates quadrate, their outer anterior outlines convex, with six radial ridges. Posterior upper (palatine) plates about 2.75 times as long as anterior plates, triangular, the posterior margin about two-thirds as long as outer margin, surface lumpy, with four prominent ridges running longitudinally. Lower (mandibular) plates nearly as long as posterior upper plates, each plate with a double concavity and central ridge on inner surface, the cutting edge uneven, highest at center of mouth.

Gill openings nearly one-half as long as distance from tip to snout to front of eye, distance across throat between their lower ends about one-half as long as eye, fold across throat strongly marked.

Dorsal spine about as long as distance from tip of snout to rear edge of pupil, reaching slightly beyond apex of first dorsal fin; outer part free from first dorsal fin, the rear face with two rows of low sharp thorns pointing toward base. First dorsal fin with sharp angle at apex and straight posterior margin; its base (from origin of spine to bottom of inter-dorsal notch) nearly as long as height along anterior margin of fin. Distance between first dorsal (when slightly depressed) and first noticeable elevation of second dorsal about two-fifths as long as anterior margin of first dorsal.

Second dorsal with horny rays easily distinguishable, upper margin nearly straight; height at midlength about one-fifth as great as length of anterior margin of first dorsal; about equally great at rear end and slightly greater toward anterior end; posterior outline of second dorsal curving abruptly downward. No definite interspace between second dorsal and upper origin of caudal. Caudal lanceolate, prolonged into a long filament about four-fifths as long as distance from snout to rear end of second dorsal; maximum height of caudal above axis about two-thirds height of second dorsal at posterior end; its extreme length to most posterior ray about 9 times as great as its height; caudal below axis about four-fifths as wide as above; the most posterior rays of both upper and lower sides of caudal terminate almost imperceptibly and about opposite each other; origin of lower side of caudal indefinite in position, preceded by a low fleshy ridge distinguishable forward to a point above and opposite beginning of last third of second dorsal fin. Pelvic fins with weakly convex anterior and distal margins, subangular outer corners and gradually rounded posterior (inner) corners; length of pelvics along anterior margin about as great as distance from tip of snout to middle of eye; origin posterior to axils of pectorals by a distance about equal to that from tip of snout to origin of pectorals. Pectoral fins about three-tenths as long as distance from tip of snout to opposite rear part of second dorsal fin; tips, when laid back, extending just beyond the base of pelvic; anterior margin weakly convex; distal margin straight or slightly concave; apex sharp pointed; inner corner broadly rounded.

Prepelvic openings present. Frontal tenaculum embedded in skin in this immature male. Claspers bifid but may develop as trifid with age.

Color.—Dark brownish everywhere on head and body above and below; fins somewhat darker.

The female closely resembles the male but lacks the prepelvic openings and, of course, the frontal tenaculum.

This species is known only from the offing of Pensacola, Fla., in a depth of 305 fathoms.

NEMATOLOGY.—*Effects of potassium nutrition and amount of inoculum on rate of reproduction of* Meloidogyne incognita. BAKIR A. OTEIFA, University of Maryland and U. S. Bureau of Plant Industry, on leave from Fouad 1, University, Giza, Egypt. (Communicated by G. Steiner.)

It is well established that nutritional conditions of host plants have a marked influence on development of various bacteria and fungi that parasitize them. As far as can be determined no information is available regarding such influence on development of parasitic nematodes. Godfrey and Oliveira (1932) have shown that the length of time required for reproduction of root-knot nematodes depends on the type of host plant used. Other authors (Chitwood, 1951; Christie, 1949) have indicated that various plant species react differently to the same nematode. In this connection question was raised whether the mineral composition of the host plant affects the reproduction of the nematode infecting it. The present study attempts to ascertain the effect of low, medium and high concentrations of potassium in a host plant upon the production of females and egg masses of the root-knot nematode, *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949, infecting it.[1]

Inoculum used in this experiment was obtained from tomato, *Lycopersicon esculentum* Mill. var. Marglobe. The number of *M. incognita* egg masses contained in a finely chopped sample of roots was counted under a binocular microscope; the corresponding weights of roots containing approximately 50 and 200 egg masses, which were the two levels of inoculum used throughout this experiment, were computed. Glazed, 3-gallon crocks were filled to one-quarter of their capacity with a coarse sand of approximately 8-mesh, on top of which a finer sand of approximately 40-mesh was added so that the pot was about half full. Chopped roots containing the required amount of inoculum in each case were distributed evenly over the surface, after which an additional layer of the finer sand was added to raise the surface to about 2 inches from the top of the crock. Seedlings of lima bean, *Phaseolus lunatus* L. var. Henderson that had been germinated in pure quartz sand were transplanted to the crocks when in the 3- or 4-leaf stage.

Composition of nutrient solutions used in the experiment is shown in Table 1. All standard compounds used were of C.P. grade. Immediately after transplanting, each crock received 250 ml of the nutrient solution desired after which additional applications of 400 to 500 ml per crock were added when needed to maintain the proper moisture level. Crocks were flushed weekly with tap water in order to prevent any accumulation of salts.

The experimental design was a randomized complete block with four replications. During the course of the experiment greenhouse temperature varied from 65° to 85°F., with an average temperature of 75°F.

After 70 days the plants had reached maturity and roots of each plant were washed free of sand and rinsed in tap water. After drainage for a few seconds, root weights were recorded and the root-gall index was determined. This index was based on the relative amount of root galling, the root system being classified as follows: 0—no evidence of galling; 1—trace of galling; 2—moderate galling; 3—extensive galling; 4—severe galling. The roots were then finely chopped and the number of females and egg masses in one gram of roots from each plant was counted. Results are given in Table 2. Examination

TABLE 1.—COMPOSITION OF NUTRIENT SOLUTIONS USED

Stock solutions	Ml stock/liter of nutrient solution		
	Low	Medium	High
M/1 $Ca(NO_3)_2$	5.0	5.0	5.0
M/1 KNO_3	0.0	5.0	5.0
M/1 $NaNO_3$	5.0	0.0	0.0
M/1 KCl	0.5	0.0	4.0
M/1 NaCl	4.0	4.5	0.5
M/1 $MgSO_4$	2.0	2.0	2.0
M/1 KH_2PO_4	0.0	1.0	1.0
M/1 NaH_2PO_4	1.0	0.0	0.0
A-Z[a]	1.0	1.0	1.0

[a] Micronutrient solution as described by Hoagland and Snyder (1933).

[1] This experiment was carried out in cooperation with the Division of Nematology, Bureau of Plant Industry, Soils, and Agricultural Engineering, Beltsville, Md.

of the data reveals that the average increase in number of females and egg masses was significant with each increase in concentration of potassium. The mean effect of increase of inoculum increment was likewise highly significant in increasing the number of females and egg masses produced.

Chitwood (1951) has shown that with certain root-attacking nematodes the mean number of females and the mean number of egg masses produced per unit of inoculum were inversely proportional to the amount of inoculum. The present results confirm this (Table 2). For each of the medium and high potassium levels it was found that an increase of egg masses in the inoculum resulted in a corresponding significant decrease in number of mature females as well as a decrease in number of egg masses produced on the test plants. However, in the cases of low potassium level this relationship was only slightly evident. This indicates that the number of egg masses produced per unit of inoculum may be influenced by the amount of potassium available.

Reproductive activities of the nematodes may be limited more by availability of potassium than by amount of root space available to the nematode. When potassium was low the average number of egg masses produced per unit of inoculum was five and the mean root weight per plant was 12 gm. When the level of potassium was medium the mean number of egg masses produced per unit of inoculum was 30, or six times as great as that of the low potassium level, while the average root weight was 27 gm or only slightly more than double the root weight for the low potassium level. When potassium level was high the mean number of egg masses produced per unit of inoculum was 32 and the root weight was 25 gm, indicating that an increase in potassium level from medium to high had little effect on the corresponding root weight and number of egg masses produced per unit inoculum. Thus while root weight increases by a factor of 2 from the low to the medium and high potassium levels the number of egg masses produced per unit inoculum increases by the factor 6.

These data indicate that the maximum number of females which the roots can support under the medium and high potassium levels was in the vicinity of 350 females per gram of root. When roots were infected to that extent the rate of reproduction, which was obtained by dividing the number of egg masses by the number of mature females, was about 0.5. Plants inoculated with 200 egg masses and given the high level of potassium did not support a greater number of females and egg masses than such plants receiving the medium level of potassium. Similar results were evident in the comparison of root gall indices of these plants. Such failure was attributed to the effects of overcrowding. When roots were not heavily infected, as in the case of plants receiving 50 units of inoculum, the number of egg masses per gram of root increased with the increase in potassium level. Rate of reproduction was

TABLE 2.—RELATIONSHIP OF POTASSIUM NUTRITION AND AMOUNT OF INOCULUM TO RATE OF REPRODUCTION OF MELOIDOGYNE INCOGNITA

Potassium levels	Units of inoculum (egg masses)	Mean root-gall index	Mean root weight	Mean number of females			Mean number of egg masses			Mean rate[c] of reproduction
				per gm root	per plant	per unit[a] inoculum	per gm per root	per gm per plant	per unit[b] inoculum	
			gm							
Low	50	3.2	9.2	117	1084	22	20	200	4	0.168
	200	3.8	15.0	246	3675	18	83	1229	6	0.334
Medium	50	2.7	32.5	126	4079	82	54	1665	32	0.428
	200	4.0	23.1	346	8034	40	196	4564	28	0.568
High	50	3.0	21.2	158	3330	67	108	2281	45	0.688
	200	4.0	21.1	361	7668	39	186	3964	20	0.514
LSD[d] .05			5.8	16.9	589.0	10.6	13.7	305.8	5.7	0.173
.01			7.8	23.2	807.8	14.6	18.8	419.3	7.9	0.236

[a] Females per plant divided by egg masses in inoculum.
[b] Egg masses per plant divided by egg masses in inoculum.
[c] Number of egg masses divided by number of mature females.
[d] Least significant differences.

also increased significantly with an increase in the 3 potassium levels: 0.168, 0.428, and 0.688, respectively.

Among plants receiving a relatively low amount of inoculum, rates of reproduction were apparently limited by the amount of potassium available, as indicated by the highly significant differences between treatments. On the other hand, with higher amounts of nematode inoculum an increase in potassium correspondingly increased the rate of reproduction up to a certain point between that produced by the medium and high levels of potassium. Thus it seems that rates of reproduction of nematodes among plants receiving medium and high levels of potassium are correlated with the amount of root available and with competition between nematodes for living space in the roots rather than the amount of potassium available.

SUMMARY

Lima-bean plants grown in sand cultures were inoculated with the root-knot nematode *Meloidogyne incognita*. Three nutrient treatments were employed supplying low, intermediate and high potassium concentrations. Two levels of nematode inoculum were used at rates of 50 and 200 egg masses.

Results of this experiment are:

1. Differences in the number of female nematodes produced on the roots and differences in the rate of their oviposition can be induced by variations in potassium concentrations.

2. Among plants receiving a relatively low amount of inoculum, rates of nematode reproduction were apparently limited by the amount of potassium available.

3. In plants receiving relatively higher inoculum and treated with higher potassium concentrations, rates of reproduction are correlated with the amount of root available and with competition between nematodes for root space rather than with the amount of potassium available.

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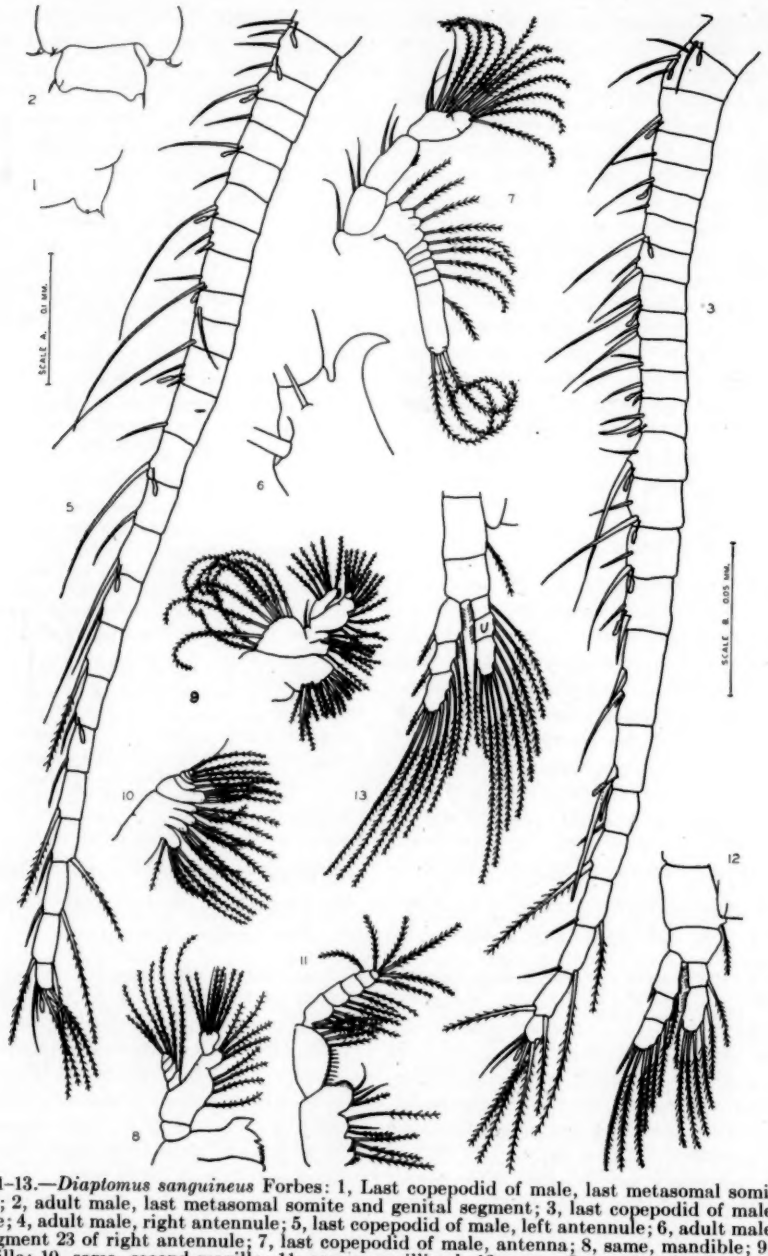
ZOOLOGY.—*The last copepodid instar of* Diaptomus sanguineus *Forbes (Copepoda).*

ARTHUR G. HUMES, Boston University, Boston, Mass., and MILDRED STRATTON WILSON, Arctic Health Research Center, Anchorage, Alaska.

The larval stages of *Diaptomus vulgaris* Schmeil have been described by Grandori (1912) and those of *D. castor* (Jurine) by Dietrich (1915) and Gurney (1931). Nauplii and copepodids of North American diaptomids, however, are almost entirely unknown. Ewers (1930) described the nauplius stages of *D. siciloides* Lilljeborg. C. B. Wilson (1932) described briefly the fifth leg of "young" male and female *D. leptopus* Forbes and the fifth leg of "undeveloped" male and female *D. oregonensis* Lilljeborg, both of these immature forms being apparently the last copepodid stage.

It is the purpose of this paper to describe the last copepodid instar of *D. sanguineus* Forbes and in so doing to supply certain details of the structure of the adult that were not mentioned in Forbes' descriptions (1876, 1882) or by later authors. Since large numbers of the last copepodid stage of both sexes may occur in plankton, along with adults of this and often other species, it is desirable to be able to correlate this immature stage with its adult form.

The specimens of *D. sanguineus* upon which the following description is based were collected from a small ice-covered pond in Weston, Mass., in February and March of 1950 and 1951. The copepods were studied entire and dissected, as stained mounts in balsam, as unstained mounts in glycerin, or



FIGS. 1–13.—*Diaptomus sanguineus* Forbes: 1, Last copepodid of male, last metasomal somite, one side only; 2, adult male, last metasomal somite and genital segment; 3, last copepodid of male, right antennule; 4, adult male, right antennule; 5, last copepodid of male, left antennule; 6, adult male, process on segment 23 of right antennule; 7, last copepodid of male, antenna; 8, same, mandible; 9, same, first maxilla; 10, same, second maxilla; 11, same, maxilliped; 12, same, first swimming leg; 13, same, second swimming leg. (All figures drawn with the aid of a camera lucida. Scale A applies to Fig. 1 only, scale B to Figs. 6, 18, and 19, and scale C to the remaining figures.)

as unstained mounts in water. The last method was most satisfactory for distinguishing the aesthetes and other minute details. Only salient points of difference between the larval and adult stages are described, since many features are better shown by figures. Specimens of both sexes of copepodids and adults have been deposited in the United States National Museum.

Last copepodid, male.—The body proportions are similar to those of the adult. The average total length and average sizes of the body regions, based upon 10 copepodid and adult males, measured without pressure, are indicated in Table 1. The metasome reaches its greatest width at the level of the second somite. The posterior lateral areas of the last somite bear a pair of sensory spines, smaller in the copepodid (Fig. 1) than in the adult male (Fig. 2). The urosome consists of four somites, as compared to five in the adult male.

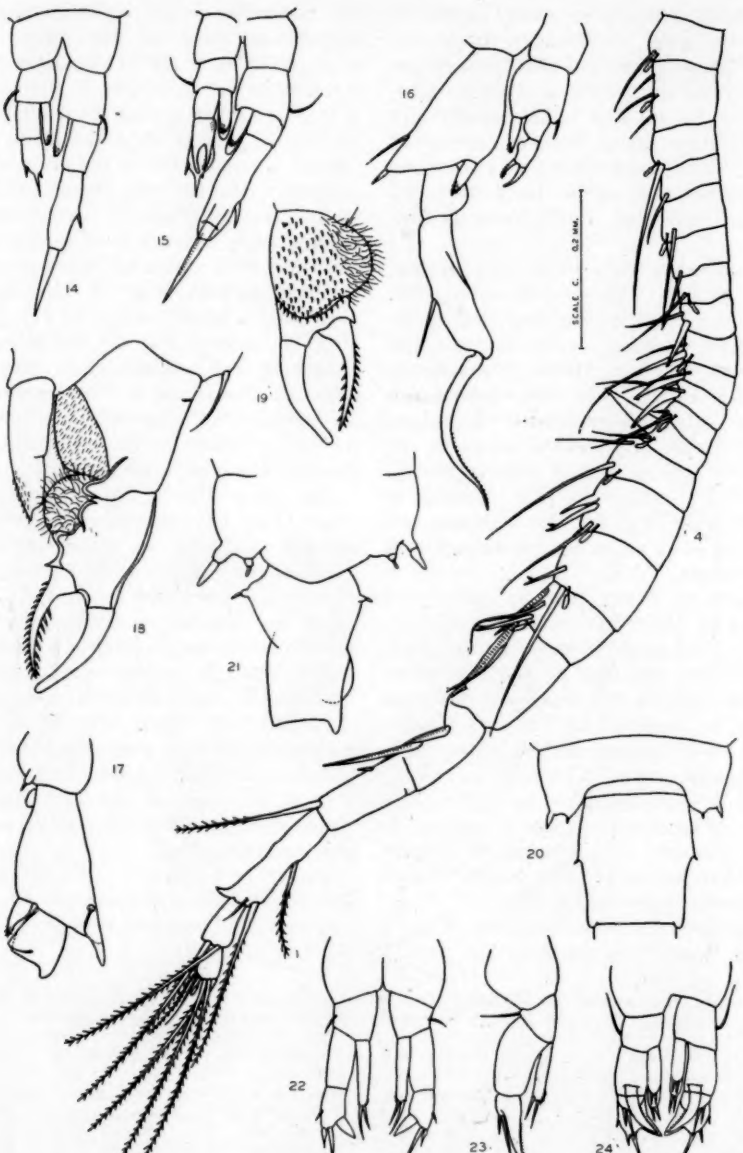
The right antennule (Fig. 3) is slenderer than that of the adult male (Fig. 4), 25-segmented, and nonprehensile. It differs from that of the left side (Fig. 5) in the presence of incipient spines and depressed processes on segments 13 and 17–19. The major spines of 8 and 10–11 are represented in the copepodid by stout setae. The right antennule of the adult is distinguished by the enlargement of the usual minor spine of segment 8, and the presence of a very stout spinous cuticular process on 15. The process of segment 23 is as shown in Fig. 6.

The antenna of the copepodid (Fig. 7) resembles that of the adult, except that in the latter the joints are somewhat more distinct and there are nine instead of eight setae on the inner side of the last endopodite podomere. The mandible of the copepodid (Fig. 8) is similar to that of the adult, except that in the palp of the latter there are nine instead of eight setae on the last endopodite podomere, and the very reduced fifth podomere of the exopodite is hardly separated. No important structural differences between the copepodid and adult were observed in the first maxilla (Fig. 9), second maxilla (Fig. 10), or maxilliped (Fig. 11). The first (Fig. 12), second (Fig. 13), third, and fourth swimming legs are similar in both instars, although the joints in the copepodid legs are less distinct. The cuticular lobe on the second podomere of the endopodite of the second leg occurs in both instars.

The right fifth leg has a single terminal spine (Fig. 14), and the left three apical spinous processes. In specimens about to molt the form of the adult leg may be seen within the copepodid form (Fig. 15). The adult leg (Fig. 16) is distinguished by the broadened second basipodite segments, that of the right side having a small, inner, proximal lamella and a distinctive elongation of the distal outer corner (Fig. 17). The apical podomere of the left exopodite has prominent chitinized areas on the anterior side (Fig. 18), that at the base of the proximal process emphasizes the extended, pointed portion of the segmental body which is of systematic importance. The pads are well developed, the proximal being medially placed and bulging, the distal confined largely to the posterior face (Fig. 19).

TABLE 1.—MEASUREMENTS (IN MICRONS) OF LAST COPEPODID AND ADULT INSTARS OF DIAPTOMUS SANGUINEUS, EACH FIGURE REPRESENTING THE AVERAGE OF 10 SPECIMENS

Body region	Copepodid male	Adult male	Copepodid female	Adult female
Total length	1367 (1287–1430)	1591 (1515–1701)	1522 (1500–1558)	1730 (1689–1773)
Head	336 × 323	361 × 342	353 × 356	391 × 387
First thoracic	130 × 323	143 × 347	145 × 351	157 × 406
Second thoracic	136 × 336	163 × 359	158 × 372	181 × 422
Third thoracic	105 × 326	123 × 352	121 × 364	140 × 409
Fourth thoracic	98 × 296	115 × 325	120 × 333	132 × 380
Fifth thoracic	87 × 257	102 × 285	107 × 289	128 × 347
Sixth thoracic	64 × 196	71 × 226	79 × 240	121 × 302
First abdominal	67 × 125	82 × 134	162 × 145	201 × 169
Second abdominal	84 × 105	104 × 100		
Third abdominal	73 × 98	96 × 93	81 × 110	65 × 98
Fourth abdominal	100 × 100	89 × 90	108 × 113	77 × 117
Fifth abdominal		64 × 98		
Caudal ramus	105 × 48	110 × 46	103 × 54	107 × 55



FIGS. 14–24.—*Diaptomus sanguineus* Forbes: 14, Last copepodid of male, fifth pair of legs; 15, same, fifth pair of legs about to molt; 16, adult male, fifth pair of legs; 17, same, basal segments of leg 5, turned somewhat mediad to show lamella of second basal segment in profile; 18, same, left fifth leg, anterior view; 19, same, left fifth leg, distal portion of exopodite, posterior view; 20, last copepodid of female, last metasomal somite and genital segment; 21, adult female, last metasomal somite and genital segment; 22, last copepodid of female, fifth pair of legs; 23, adult female, fifth leg; 24, last copepodid of female, fifth pair of legs about to molt.

Last copepodid, female.—The outline of the body is similar to that of the male. The average measurements for both copepodid and adult females, corresponding to those given for the male, are indicated in Table 1. The pair of sensilla on each side of the last metasomal somite (Fig. 20) are smaller than the prominent ones of the adult (Fig. 21) which are highly characteristic of *D. sanguineus*. The urosome in both instars consists of three somites. The genital segment of the copepodid (Fig. 20) is simple, but that of the adult is elongate and asymmetrical (Fig. 21).

The right and left antennules are similar in both instars, resembling the nonprehensile appendages of the males. The species is of the "little setaceous" type, having only one seta on segments 11 and 13–19. The antennae and mandibles differ in the two instars in the same way as in the male. The first and second maxillae, maxillipeds, and first through fourth legs are similar to those of the male.

The fifth leg in the copepodid (Fig. 22) differs from the adult in the presence of the lateral seta of the second exopodite podomere. The prominent claw of the adult (Fig. 23) is weakly developed. In specimens about to molt the form of the adult female may be seen within (Fig. 24).

The principal points of difference between the last copepodid and the adult stages, aside from changes in body size and proportions, are found in both sexes in the development of the sensilla of the last metasomal somite, in the number of terminal setae on the endopodites of the antennae and the mandibles, and in the form of the fifth legs. The male is further distinguished by the number of somites in the urosome, and by the structure of the right antennule. The female differs conspicuously in the development of the genital segment.

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BOTANY.—*A study of the roots of Pinus virginiana in relation to certain Hymenomycetes suspected of being mycorrhizal.* EDWARD HACSKAYLO, George Washington University. (Communicated by William W. Diehl.)

The occurrence of ectotrophic mycorrhizae on *Pinus virginiana* Mill., a common conifer of the eastern United States, has been referred to by Henry (1), Kelley (2), McComb (4), and McDougall (5), but no mention was made concerning the identity of the fungi involved in the relationship with this tree species. Inasmuch as fungal cultures could be obtained from sporophores collected from a stand of pine, it would be possible to determine experimentally the identity of some of those species associated in the mycorrhizae of *P. virginiana*. This could be accomplished by subjecting seedlings germinated under aseptic conditions to simple inoculation tests using pure cultures of each fungus suspected because of its constant association with the pine stands.

Sporophores of several Hymenomycetes were collected during the summer and fall of 1949 from two nearly pure stands of *Pinus virginiana* occurring in Virginia near Washington, D. C. The following fungi were identified: *Amanita verna* (Bull.) Quel., *Boletus americanus* Pk., *Boletus* sp., *Clavaria pulchra* Pk., *Lactarius chrysorrheus* Fr., *L. piperatus* (Scop.) Fr., *Tricholoma equestre* (L.) Quel., and *T. portentosum* Fr. From young sporophores of the above, tissue fragment cultures were obtained on a 50–50 mixture of commercial potato dextrose and malt dextrose agars.

Seeds of *Pinus virginiana*, purchased from the Herbst Brothers Seed Co., of New York, were surface-sterilized by soaking them for five minutes in a 1:1000 aqueous solution of bichloride of mercury. Following this treatment, the seeds were washed four times with sterile deionized water and then placed on a 2% (Ben Venue[1] green plant) agar medium containing the following amounts of salts per liter: $MgSO_4$, 1.2 gm; $(NH_4)_2SO_4$, 0.2 gm; $Ca(NO_3)_2$, 0.8 gm; KH_2PO_4, 0.7 gm and a trace of $CuSO_4$. They were germinated aseptically in Petri dishes and urine specimen bottles in a room at approximately 24°C. not exposed to direct sunlight.

In January and February, 1950, 100 pot cultures of pine seedlings were inoculated with the various fungi in culture, and 16 uninoculated controls were prepared. The methods used were similar to those described by McArdle (3) modified as follows. Each 3-inch pot was equipped with a glass subirrigation tube in order to avoid washing surface contaminants into the substrate during watering and applying nutrient solution to the cultures. The end of tube exposed to the air was covered with a glass vial when not in use. The system tended to reduce the amount of moisture on the substrate surface and consequently was not favorable for air-borne contaminants. The nutrient solution used was the same as prescribed by McArdle (3).

The pot cultures were maintained in the greenhouse where growth was generally favorable. There was, however, some variation in the amount of shoot growth among the different cultures.

In April 1950, examination of some of the roots showed profuse dichotomy of the short roots, this having developed in less than four months in cultures containing mycelium of *Amanita verna*. Dichotomy was also present to a lesser extent in the cultures containing mycelium of *Lactarius piperatus* and *Tricholoma portentosum*, but not in the pots containing the other fungi noted above. In free-hand sections of these dichotomous roots, it was found that initials of ectotrophic mycorrhizae had developed since mantles were present. Hyphal penetration was not evident as a well-developed Hartig net. Roots of eight of the control plants were examined and neither dichotomy nor fungus association was found.

The roots of seedlings that were maintained and examined after a period of six to eight months did not appear to be growing actively during late spring and summer. There were neither mycorrhizal nor nonmycorrhizal young roots and very few older structures that resembled mycorrhizae. High temperatures up to 46°C. noted in the greenhouse after April 1 may have inhibited mycorrhizal formation and root development.

These results indicate that *Amanita verna*, *Lactarius piperatus*, and *Tricholoma portentosum* are possibly involved in the mycorrhizae of *Pinus virginiana*. No such indications, however, were found with *Boletus americanus*, *Boletus* sp., *Clavaria pulchra*, *Lactarius chrysorrheus*, and *Tricholoma equestre* under the conditions of the experiment. None of the roots of the control plants were found to be associated with a fungus. This work has revealed some of the problems that must be solved in future experimentation and is a forerunner of research now under way.

[1] Ben Venue Laboratories, Bedford, Ohio.

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INDEX TO VOLUME 41

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

Anthropological Society of Washington. 307.

Washington Academy of Sciences. 48, 115, 148, 238.

AUTHOR INDEX

ABBOTT, DONALD P. *Bostrichobranchus digonas*, a new molgulid ascidian from Florida. 302.

ABBOTT, R. TUCKER. New stenothyrid gastropods from the Philippines (Rissoidae). 14.

—— and LADD, H. S. A new brackish-water gastropod from Texas (Amnicolidae: Littoridina). 335.

——. See also REHDER, HARALD. 22.

ALLARD, H. A. *Dinoponera gigantea* (Perty), a vicious stinging ant. 88.

ARCHER, W. ANDREW. See JENKINS, ANNA E. 66.

BARTSCH, PAUL. More urocoptid mollusks from Mexico. 146.

BAYER, FREDERICK M. A revision of the nomenclature of the Gorgoniidae (Coelenterata: Octocorallia), with an illustrated key to the genera. 91.

——. Two new primnoïd corals of the subfamily Calyptrophorinae (Coelenterata: Octocorallia). 40.

BEHLE, WILLIAM H., and SELANDER, ROBERT J. The systematic relationships of the fox sparrows (*Passerella iliaca*) of the Wasatch Mountains, Utah, and the Great Basin. 364.

BERKELEY, E. and C. A second record of the polychaetous annelid *Potamethus elongatus* (Treadwell). 333.

BIGELOW, HENRY B., and SCHROEDER, WILLIAM C. Three new skates and a new chimaerid fish from the Gulf of Mexico. 383.

——. A new genus and species of anacanthobatid skate from the Gulf of Mexico. 110.

BITANCOURT, A. A. See JENKINS, ANNA E. 66.

BLAKE, DORIS H. New species of chrysomelid beetles of the genera *Trirhabda* and *Disonycha*. 324.

BURLEY, GORDON. See KRACEK, F. C. 373.

CAMPBELL, T. N. Medicinal plants used by Choctaw, Chickasaw, and Creek Indians in the early nineteenth century. 285.

CARR, LLOYD G. K. Interesting animal foods, medicines, and omens of the eastern Indians, with comparisons to ancient European practices. 229.

CHACE, FENNER A., JR. The grass shrimps of the genus *Hippolyte* from the west coast of North America. 35.

——. The number of species of decapod and stomatopod Crustacea. 370.

CAUSEY, NELL B. New cleidogonid millipeds (Chordeumoidea). 78.

CHALKLEY, H. W. See CORNFIELD, JEROME. 226.

CLARK, AUSTIN H. The brittle-stars of the United States Navy Antarctic Expedition 1947–48. 26.

CLARKE, J. F. GATES. A new genus and species of North American Olethreutidae (Lepidoptera: Laspeyresiinae). 46.

——. New species of Gelechiidae from Argentina (Lepidoptera). 140.

——. New species of Olethreutidae from Argentina. 296.

COE, WESLEY R. Geographical distribution of the nemerteans of the northern coast of the Gulf of Mexico as compared with those of the southern coast of Florida, with descriptions of three new species. 328.

COOPER, G. ARTHUR. New brachiopods from the Lower Cambrian of Virginia. 4.

—— and MUIR-WOOD, HELEN M. Brachiopod homonyms. 195.

CORNFIELD, JEROME, and CHALKLEY, HAROLD W. A problem in geometric probability. 226.

CURTIN, PHILIP D. A survey of new archeological sites in central Pataz, Peru. 49.

DALQUEST, WALTER W. Six new mammals from the state of San Luis Potosí, Mexico. 361.

DAVENPORT, DESMOREST. See LOOMIS, H. F. 270.

DEXTER, RALPH W. See SPECK, FRANK G. 250.

DRAKE, CARL J. New American chinch bugs (Hemiptera: Lygaeidae). 319.

DUNKLE, DAVID H. New Western Hemisphere occurrences of fossil selachians. 344.

DURBIN, CHARLES G., and HONESS, RALPH F. A new roundworm, *Nematodirus rufaevastitatis* (Nematoda: Trichostrongylidae), from domestic sheep, *Ovis aries*, in Wyoming. 179.

EMERSON, WILLIAM K. A new scaphopod mollusk, *Cadulus austinclarki*, from the Gulf of California. 24.

FRIEDMANN, HERBERT. Dedication [to Austin Hobart Clark issue). 1.

GARDNER, JULIA. Two new guide fossils from the Tallahatta formation of the Southeastern States. 8.

GRYC, GEORGE, PATTON, W. W., JR., and PAYNE, T. G. Present Cretaceous stratigraphic nomenclature of northern Alaska. 159.

GWILLIAM, G. F. See HAND, CADET. 206.

HAAS, VICTOR H. Disaster and disease, 277.

HACKMAN, ROBERT J. See SOLECKI, RALPH S. 85.

HACSKAYLO, EDWARD. A study of the roots of *Pinus virginiana* in relation to certain Hymenomycetes suspected of being mycorrhizal. 399.

HAND, CADET, and GWILLIAM, G. F. New distributional records for two athecate hydroids, *Cordylophora lacustris* and *Candelabrum* sp., from the west coast of North America, with revisions of their nomenclature. 206.

HEYL, PAUL R. The limitations of the principle of superposition, II. 149.

HOBBS, HORTON H., JR. A new crayfish of the genus *Procambarus* from Louisiana, with a key to the species of the *Spiculifer* group. 272.

HOFFMAN, RICHARD L. The diplopod family Campodesmidae (Polydesmida). 209.

HONESS, RALPH F. See DURBIN, CHARLES G. 179.

HUMES, ARTHUR G., and WILSON, MILDRED STRATTON. The last copepodid instar of *Diatomus sanguineus* Forbes (Copepoda). 395.

ILLG, PAUL L. A new genus and species of notodelphyoid copepod from Japan. 30.

JENKINS, ANNA E., BITANCOURT, A. A., SILBERSCHMIDT, K., and ARCHER, W. ANDREW. Peter Wilhelm Lund's pequi tree at Lagoa Santa and pilgrimages to his cemetery. 66.

JOHNSTON, FRANCIS E. The theory of group representations. 117.

KENG, HSÜAN. New or critical Euphorbiaceae from eastern Asia. 200.

KRACEK, F. C., NEUVONEN, K. J., and BURLEY, GORDON. Thermochemistry of mineral substances, I: A thermodynamic study of the stability of jadeite. 373.

KRISHNASWAMY, K. Notes on the undescribed males of two species of Copepoda. 75.

LADD, H. S. See ABBOTT, R. TUCKER. 335.

LLANO, GEORGE A. A contribution to the lichen flora of Alaska. 196.

LOOMIS, H. F., and DAVENPORT, DEMOREST. A luminescent new xystodesmid milliped from California. 270.

MACNEIL, F. STEARNS. *Nucula austinclarki*, n. sp., a concentrically sculptured *Nucula* from the Lisbon formation of Alabama. 12.

MILLER, ROBERT RUSH, and WINN, HOWARD ELLIOTT. Additions to the known fish fauna of of Mexico: Three species and one subspecies from Sonora. 83.

MITRINOVITCH, D. S. On an equation of Neményi and Truesdell. 129.

MORRISON, J. P. E. Two new Western Atlantic species of pulmonate mollusks of the genus *Detracia* and two old ones (family Ellobiidae). 17.

MORTON, C. V. A new fern of the genus *Danaea* from Colombia. 276.

MUIR-WOOD, HELEN M. See COOPER, G. A. 195.

NEUVONEN, K. J. See KRACEK, F. C. 373.

NICOL, DAVID. A new species of glycymerid from the Philippines. 20.

———. Recent species of the cyrenoid pelecypod *Glossus*. 142.

———. Recent species of the veneroid pelecypod *Arctica*. 102.

OTEIFA, BAKIR A. Effects of potassium nutrition and amount of inoculum on rate of reproduction of *Meloidogyne incognita*. 393.

PATE, CHESTER H. Information theory. 245.

PATTON, W. W., JR. See GRYC, GEORGE. 159.

PAYNE, T. G. See GRYC, GEORGE. 159.

PETTIBONE, MARIAN H. A new species of polychaete worm of the family Polynoidae from Point Barrow, Alaska. 44.

PITELKA, FRANK A. Race names in the Central American jay, *Cyanolyca argentigula*. 113.

PRATT, HARRY D. *Ficalbia minima* (Theobald) in South Indochina, with descriptions of the larva and pupa (Diptera: Culicidae). 300.

REEDER, JOHN R. A new species of *Poa* from Peru. 295.

REHDER, HARALD A., and ABBOTT, R. TUCKER. Two new Recent cone shells from the Western Atlantic (Conidae). 22.

RIOUX, MARCEL. Some medical beliefs and practices of the contemporary Iroquois Longhouses of the Six Nations Reserve. 152.

ROSS, HERBERT H. Phylogeny and biogeography of the caddisflies of the genera *Agapetus* and *Electragapetus* (Trichoptera: Rhyacophilidae). 347.

SAVAGE, JAY M. Studies on the lizard family Xantusiidae, II: Geographical variation in *Xantusia riversiana* from the Channel Islands of California. 357.

SCHAEFFER, CLAUDE E. Was the California condor known to the Blackfoot Indians? 181.

SCHMITT, W. L. [Biographical Résumé, of Austin Hobart Clark.] 3.

SCHROEDER, W. C. See BIGELOW, H. B. 110, 383.

SCHULTZ, LEONARD P., and SIMÕES DE MENEZES, RUI. A new anchovy of the genus *Anchoviella* from the Poti and Parnaiba Rivers of Brazil. 235.

———. See also WELANDER, ARTHUR D. 107.

SELANDER, R. K. See BEHLE, WILLIAM H. 364.

SILBERSCHMIDT, K. See JENKINS, ANNA E. 66.

SILSBEE, FRANCIS B. Measure for measure: Some problems and paradoxes of precision. 213.

SIMÕES DE MENEZES, RUI. See SCHULTZ, LEONARD P. 235.

SOHN, I. G. Check list of salinity tolerance of post-Paleozoic fossil Ostracoda. 64.

SOLECKI, RALPH S. and HACKMAN, ROBERT J. Additional data on the Denbigh Flint Complex in northern Alaska. 85.

SOULE, JOHN D. Two new species of incrusting ctenostomatous Bryozoa from the Pacific. 367.

SPECK, FRANK G., and DEXTER, RALPH W. Utilization of animals and plants by the Micmac Indians of New Brunswick. 250.

SPITZER, LYMAN, JR. The birth of stars from interstellar clouds. 309.

STAINBROOK, MERRILL A. Substitution for the preoccupied name *Hystricina*. 196.

STRIMPLE, HARRELL L. New crinoids from the Pitkin of Oklahoma, 260.

———. New Desmoinesian crinoids. 191.

———. Notes on *Phanocrinus cylindricus* and description of new species of Chester crinoids. 291.

TAWADA, SHINJUN. See WALKER, EGBERT H. 138.

TIMM, R. W. A new species of marine nematode, *Thoracostoma magnificum*, with a note on possible "pigment cell" nuclei of the ocelli. 331.

TIPTON, VERNON J. See TRAUB, ROBERT. 264.

TRAGER, GEORGE L. Linguistic history and ethnologic history in the Southwest. 341.

TRAUB, ROBERT, and TIPTON, VERNON J. *Jordanopsylla allredi*, a new genus and species of flea from Utah (Siphonaptera). 264.

WALKER, EGBERT, and TAWADA, SHINJUN. A new species of *Portulaca* from Okinawa. 138.

WEDEL, WALDO R. Notes on aboriginal pottery from Montana. 130.

WELANDER, ARTHUR D., and SCHULTZ, LEONARD P. *Chromis atripectoralis*, a new damselfish from the tropical Pacific, closely related to *C. caeruleus*, family Pomacentridae. 107.

WETMORE, ALEXANDER. Observations on the genera of the swans. 338.

WILSON, MILDRED STRATTON. A new subgenus of *Diaptomus* (Copepoda: Calanoida), including an Asiatic species and a new species from Alaska. 168.

———. See also HUMES, ARTHUR G. 395.

WINN, HOWARD ELLIOTT. See MILLER, ROBERT RUSH. 83.

SUBJECT INDEX

Archeology. Additional data on the Denbigh Flint Complex in northern Alaska. RALPH S. SOLECKI and ROBERT J. HACKMAN. 85.
A survey of new archeological sites in central Pataz, Peru. PHILIP D. CURTIN. 49.
Notes on aboriginal pottery from Montana. WALDO R. WEDEL. 130.
Astronomy. The birth of stars from interstellar clouds. LYMAN SPITZER, JR. 309.
Biography. Biographical sketch and portrait of Austin Hobart Clark. 2–3.
Botany. A contribution to the lichen flora of Alaska. GEORGE A. LLANO. 196.
A new fern of the genus *Danaea* from Colombia. C. V. MORTON. 276.
A new species of *Poa* from Peru. JOHN R. REEDER. 295.
A new species of *Portulaca* from Okinawa. EGBERT H. WALKER and SHINJUN TAWADA. 138.
A study of the roots of *Pinus virginiana* in relation to certain Hymenomycetes suspected of being mycorrhizal. EDWARD HACSKAYLO. 399.
New or critical Euphorbiaceae from eastern Asia. HSÜAN KENG. 200.
Peter Wilhelm Lund's pequi tree at Lagoa Santa and pilgrimages to his cemetery. ANNA E. JENKINS, A. A. BITANCOURT, K. SILBERSCHMIDT, and W. A. ARCHER. 66.
Entomology. A new genus and species of North American Olethreutidae (Lepidopter : Laspeyresiinae). J. F. GATES CLARKE. 46.
Dinoponera gigantea (Perty), a vicious stinging ant. H. A. ALLARD. 88.
Ficalbia minima (Theobald) in South Indochina, with descriptions of the larva and pupa (Diptera: Culicidae). HARRY D. PRATT. 300.
Jordanopsylla allredi, a new genus and species of flea from Utah (Siphonaptera). ROBERT TRAUB and VERNON J. TIPTON. 264.
New American chinch bugs (Hemiptera: Lygaeidae). CARL J. DRAKE. 319.
New species of chrysomelid beetles of the genera *Trirhabda* and *Disonycha*. DORIS H. BLAKE. 324.
New species of Gelechiidae from Argentina (Lepidoptera). J. F. GATES CLARKE. 140.
New species of Olethreutidae from Argentina (Lepidoptera). J. F. GATES CLARKE. 296.
Phylogeny and biogeography of the caddisflies of the genera *Agapetus* and *Electragapetus* (Trichoptera: Rhyacophilidae). HERBERT H. ROSS. 347.
Ethnology. Interesting animal foods, medicines, and omens of the eastern Indians, with comparisons to ancient European practices. LLOYD G. K. CARR. 229.
Linguistic history and ethnologic history in the Southwest. GEORGE L. TRAGER. 341.
Medicinal plants used by the Choctaw, Chickasaw, and Creek Indians in the early nineteenth century. T. N. CAMPBELL. 285.
Some medical beliefs and practices of the contemporary Iroquois Longhouses of the Six Nations Reserve. MARCEL RIOUX. 152.
Utilization of animals and plants by the Micmac Indians of New Brunswick. FRANK G. SPECK and RALPH W. DEXTER. 250.
Was the California condor known to the Blackfoot Indians? CLAUDE E. SCHAEFFER. 181.
Geology. Present Cretaceous stratigraphic nomenclature of northern Alaska. GEORGE GRYC, W. W. PATTON, JR., and T. G. PAYNE. 159.
Helminthology. A new roundworm, *Nematodirus rufaevastitatis* (Nematoda: Trichostrongylidae), from domestic sheep, *Ovis aries*, in Wyoming. CHARLES G. DURBIN and RALPH F. HONESS. 179.
Herpetology. Studies of the lizard family Xantusiidae, II: Geographical variation in *Xantusia riversiana* from the Channel Islands of California. JAY M. SAVAGE. 357.
Ichthyology. Additions to the known fish fauna of Mexico: Three species and one subspecies from Sonora. ROBERT RUSH MILLER and HOWARD ELLIOTT WINN. 83.
A new anchovy of the genus *Anchoviella* from the Poti and Parnaiba Rivers of Brazil. LEONARD P. SCHULTZ and RUI SIMÕES DE MENEZES. 235.
A new genus and species of anacanthobatid skate from the Gulf of Mexico. HENRY B. BIGELOW and WILLIAM C. SCHROEDER. 110.
Chromis atripectoralis, a new damselfish from the tropical Pacific, closely related to *C. caeruleus*, family Pomacentridae. ARTHUR D. WELANDER and L. P. SCHULTZ. 107.
Three new skates and a new chimaerid fish from the Gulf of Mexico. HENRY B. BIGELOW and WILLIAM C. SCHROEDER. 383.
Malacology. A new brackish-water gastropod from Texas (Amnicolidae: Littoridina). R. T. ABBOTT and H. S. LADD. 335.
A new scaphopod mollusk, *Cadulus austinclarki*, from the Gulf of California. WILLIAM K. EMERSON. 24.
A new species of glycymerid from the Philippines. DAVID NICOL. 20.
More new urocoptid mollusks from Mexico. PAUL BARTSCH. 146.
New stenothyrid gastropods from the Philippines (Rissoidae). R. TUCKER ABBOTT. 14.
Recent species of the cyrenoid pelecypod *Glossus*. DAVID NICOL. 142.
Recent species of the veneroid pelecypod *Arctica*. DAVID NICOL. 102.
Two new Recent cone shells from the Western Atlantic (Conidae). HARALD A. REHDER and R. TUCKER ABBOTT. 22.
Two new Western Atlantic species of pulmonate mollusks of the genus *Detracia* and two old ones (family Ellobiidae). J. P. E. MORRISON. 17.
Mammalogy. Six new mammals from the state of San Luis Potasí, Mexico. WALTER W. DALQUEST. 361.
Mathematics. A problem in geometric probability. JEROME CORNFIELD and HAROLD W. CHALKLEY. 226.

Mathematics. Information theory. CHESTER H. PAGE. 25.

On an equation of Neményi and Truesdell. D. S. MITRINOVITCH. 129.

The theory of group representations. FRANCIS E. JOHNSTON. 117.

Medicine. Disaster and disease. V. H. HAAS. 277.

Nematology. Effects of potassium nutrition and amount of inoculum on rate of reproduction of *Meloidogyne incognita*. B. A. OTEIFA. 393.

Ornithology. Observations on the genera of the swans. ALEXANDER WETMORE. 338.

Race names in the Central American jay, *Cyanolyca argentigula*. FRANK A. PITELKA. 113.

The systematic relationships of the fox sparrows (*Passerella iliaca*) of the Wasatch Mountains, Utah, and the Great Basin. W. H. BEHLE and R. K. SELANDER. 364.

Paleontology. Brachiopod homonyms. G. ARTHUR COOPER and HELEN M. MUIR-WOOD. 195.

Check list of salinity tolerance of post-Paleozoic fossil Ostracoda. I. G. SOHN. 64.

New brachiopods from the Lower Cambrian of Virginia. G. ARTHUR COOPER. 4.

New crinoids from the Pitkin of Oklahoma. HARRELL L. STRIMPLE. 260.

New Desmoinesian crinoids. HARRELL L. STRIMPLE. 191.

New Western Hemisphere occurrences of fossil selachians. DAVID H. DUNKLE. 344.

Notes on *Phanocrinus cylindricus* and description of new species of Chester crinoids. HARRELL L. STRIMPLE. 291.

Nucula austinclarki, n. sp., a concentrically sculptured *Nucula* from the Lisbon formation of Alabama. F. STEARNS MACNEIL. 12.

Substitution for the preoccupied name *Hystricina*. MERRILL A. STAINBROOK. 196.

Two new guide fossils from the Tallahatta formation of the Southeastern States. JULIA GARDNER. 8.

Petrology. Thermochemistry of mineral substances, I: A thermodynamic study of the stability of jadeite. F. C. KRACEK, K. J. NEUVONEN, and GORDON BURLEY. 373.

Physics. Measure for measure: Some problems and paradoxes of precision. F. B. SILSBEE. 213.

The limitations of the principle of superposition: II. PAUL R. HEYL. 149.

Zoology. A luminescent new xystodesmid milliped from California. H. F. LOOMIS and DEMOREST DAVENPORT. 270.

A new crayfish of the genus *Procambarus* from Louisiana, with a key to the species of the *Spiculifer* group. H. H. HOBBS, JR. 272.

Zoology. A new genus and species of notodelphyoid copepod from Japan. PAUL L. ILLG. 30.

A new species of marine nematode, *Thoracostoma magnificum*, with a note on possible "pigment cell" nuclei of the ocelli. R. W. TIMM. 331.

A new species of polychaete worm of the family Polynoidae from Point Barrow, Alaska. MARIAN H. PETTIBONE. 44.

A new subgenus of *Diaptomus* (Copepoda: Calanoida), including an Asiatic species and a new species from Alaska. MILDRED STRATTON WILSON. 168.

A revision of the nomenclature of the Gorgoniidae (Coelenterata: Octocorallia), with an illustrated key to the genera. FREDERICK M. BAYER. 91.

A second record of the polychaetous annelid *Potamethus elongatus* (Treadwell). E. and C. BERKELEY. 333.

Bostrichobranchus digonas, a new molgulid ascidian from Florida. D. P. ABBOTT. 302.

Geographical distribution of the nemerteans of the northern coast of the Gulf of Mexico as compared with those of the southern coast of Florida, with descriptions of three new species. WESLEY R. COE. 328.

New cleidogonid millipeds (Chordeumoidea). NELL B. CAUSEY. 78.

New distributional records for two athecate hydroids, *Cordylophora lacustris* and *Candelabrum* sp., from the west coast of North America, with revisions of their nomenclature. CADET HAND and G. F. GWILLIAM. 206.

Notes on the undescribed males of two species of Copepoda. S. KRISHNASWAMY. 75.

The brittle-stars of the United States Navy Antarctic Expedition 1947–48. AUSTIN H. CLARK. 26.

The diplopod family Campodesmidae (Polydesmida). RICHARD L. HOFFMAN. 209.

The grass shrimps of the genus *Hippolyte* from the west coast of North America. FENNER A. CHACE, JR. 35.

The last copepodid instar of *Diaptomus sanguineus* Forbes (Copepoda). ARTHUR G. HUMES and MILDRED S. WILSON. 395.

The number of species of decapod and stomatopod Crustacea. F. A. CHACE, JR. 370.

Two new primnoïd corals of the subfamily Calyptrophorinae (Coelenterata: Octocorallia). FREDERICK M. BAYER. 40.

Two new species of incrusting ctenostomatous Bryozoa from the Pacific. J. D. SOULE. 367.